THE SCIENTIFIC HABIT OF THOUGHT

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AN INFORMAL DISCUSSION OF THE SOURCE AND CHARACTER OF DEPENDABLE KNOWLEDGE

BY

FREDERICK BARRY

Research Associate in Calorimetry
Assistant Professor of the History of Science
in Columbia University

NEW YORK
COLUMBIA UNIVERSITY PRESS
1927

5604

Set up and electrotyped. Published September, 1927

PRINTED IN THE UNITED STATES OF AMERICA

To

A. B. B.

whose thought
originally gave form to
all this matter

"Without an understanding of natural science and technology in their own terms, understanding is external, arbitrary, and criticism is 'transcendent' and ultimately of one's own private conceit."

JOHN DEWEY.

PREFACE

The content of this book is precisely indicated by its title; its purpose and tenor by its subtitle; its occasion and possible justification by the passage written on the preceding page, which I have ventured to quote from Professor Dewey.

At no time in the past has common interest in scientific matters been as spontaneous and appreciative as it is to-day. The humanistic interests of all intelligent people are becoming more and more inclusive, and are guided by a newly enlightened judgment concerning relative values which directs attention more frequently than ever before to the scientific signification of every thought and act. It is clear that if this wholesome cultural impulse is to be effectively encouraged, no effort should be spared to assist in its intelligent direction; and it goes without saying that since the whole movement centers in the demand for scientific knowledge, then, while this knowledge is being imparted it is very important that it be correctly interpreted, unless the effect of its widespread dissemination is to be socially profitless or morally equivocal through misapprehension of its significance. From the humanistic as well as from the purely intellectual point of view, in fact, the general acquisition of scientific knowledge is of far less consequence than the inculcation of the scientific habit of thought.

Our general literature does not lack interpretations of scientific thought. The most influential of these, however, are essentially irrelevant and, in this sense, incompetent. The productive natural scientist himself has done little to impart to the people at large the living spirit which animates his labor, the instinctive philosophy which guides it, or the methods which make it effective; and the theorists who venture most persuasively to repair his error of neglect are usually onlookers quite innocent of experience in practical research, whose mental predisposition is the antithesis of his own, and who, therefore, too frequently misrepresent it. Their expositions have already accomplished much toward the general befuddlement of common thought concerning science; even more, one is inclined to believe, than the entertaining misinformation which is desseminated as news. Between the Scylla of journalism and the Charybdis of transcendental metaphysics, the unskilled voyager in these troubled waters is now in a most unhappy situation; and it appears to be well worth while to offer him a little professional assistance.

For lack of more effective means, these essays have been written. They embody the substance of casual notes which were taken down at intervals during four years of collegiate teaching in the history of science, and summarize the answers made to insistent questions repeatedly asked during lectures and in conference. In the nature of the case they are fragmentary, and convey more than one might desire by suggestion merely; but, having been arranged in quasi-logical sequence, they appear to include introductory discus-

sions of all important aspects of the scientific habit of thought, sufficiently detailed to correct false impressions both natural and recently acquired, and perhaps to stimulate by implication a little further reflection. They have been made untechnical and (perhaps unduly) explanatory, with deliberation; and their informal tone has been allowed quite naturally to reflect the buoyant and somewhat easy-going manner of the laboratory rather than that of the lecture-room. Even their reiterations, which are outcroppings of similar general ideas in different contexts, have been allowed to stand, in the expectation that they are not unlikely to serve the purposes of explanation. The professional reader who gives these pages his accidental attention, therefore, may find them somewhat too discursive to suit his taste. He will observe, however, that their substance embodies a well-defined thesis derived from first-hand experience which in itself lacks nothing of earnestness and conviction, and which might without effort be defended in detail by more explicit argument. For the rest, every grown-up person will realize that there exists a higher order of seriousness than that of the personal concern which is reflected in severe demeanor.

New York City,
December, 1926.

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SCIENCE AND THE SCIENCES

I

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In cultivated usage, science means knowledge or rational conjecture which tentatively may be accepted as knowledge. The term is very inclusive. It calls to mind immediately those great bodies of interwoven fact and hypothesis which together comprise our knowledge and opinion concerning the world of nature — the external world. Astronomy and physics, chemistry, geology and biology: these are the sciences *par excellence*. But we call psychology also a science, though the facts which are its primary concern are not usually looked upon (by any but certain psychologists and philosophers) as objective facts at all, but as what are still called states of mind: emotions, volitions, ideas. Furthermore, we speak habitually of the political and social sciences: vast complexes of facts at once physical and mental, of a distinctive character in many ways unanalyzable. The methods of these sciences are as various as the facts with which they deal, and their organizations range from those of exact and inclusive correlation in terms of sharply definable concepts to those of loose classification or of mere description.

In a different sense entirely we speak of the sciences of logic and mathematics. These sciences, as independent disciplines, do not concern themselves with physical or vital facts of any sort, but deal exclusively with

the interrelations of abstract ideas; and in their chaste maturity with relations merely, in complete disregard even of the meanings of terms. The abstractions of things and events may themselves be abstracted, to yield undefinable invariants: these in relation constitute pure logic and mathematics, which thus become in a philosophical sense the sciences of pure form, possibly applicable to real physical existence, but not a part of it. These sciences are related to the physical, biological and anthropological sciences, therefore, only through their formulation of the procedures of deductive inference. They are, in fact, commonly referred to as the sciences of method: a designation which is correct, though too general.

In common parlance, science is still less sharply defined. Engineering and medicine, which are highly developed practical arts based to a large extent upon techniques and opinions which are theoretically defensible or verifiable, are ordinarily spoken of as sciences; and by a similar but more imaginative metonymy, a great variety of other arduous occupations which may not be successfully prosecuted by the untrained — such as business management, polar exploration, advertising or pugilism — are frequently referred to in like manner, though to the superficial view they sometimes appear to be little else than sports. But, from this extended category, oddly enough, the work of the mechanic, which in its higher development is altogether the most exacting, and actually determines in the end the final precision of all scientific observation, seems by common consent to be excluded. Quite as remarkably, also, the fine arts, which demand

a still more subtle kind of skill, have seldom been called sciences, and story-telling and poetry never; despite the fact that not so very long ago they possessed techniques — drawing, orchestration, rhetoric and prosody — which involved the application of principles universally recognized as scientific. Popular usage in this matter thus appears to be somewhat whimsical; and yet it yields upon easy analysis the very essence of the word. It is clear, for instance, that we classify business management, pugilism and medicine together as sciences because, though as occupations they are only incidentally related, they are all characterized by the practical, methodical, and so far as is humanly possible, the rational utilization of knowledge for the attainment of definite results. It is noteworthy, also, that these results are usually satisfactory ends in themselves. We exclude shop-work, probably, because its productions have no such independent value or because they are not so obviously consequential. We exclude the fine arts and *belles-lettres,* however, on other grounds: and in this case the working of the popular mind appears to be more subtle.

Works of art have a value which, even when it is not recognized, is usually conceded; and this value is not infrequently highly practical. It is the spirit rather than the achievement of the artist, musician or poet which is unscientific. In the first place, he seems possessed of a veritable mania for the concealment of his method and technique; and this secretiveness is antagonistic to both the temper and the habit of scientists and sportsmen. On this account alone he might not be excluded from the fraternity: the old Greek

geometers were equally uncommunicative. But they who practice the fine arts more closely resemble the pseudo-scientists — alchemists, necromancers and their ilk — than men like these. Their furtive instincts are no mere temperamental idiosyncracies but are dominant group characteristics, self-consciously cultivated and technically elaborated in forms of expression which are carefully chosen to make the products of their labor suggestive rather than informing. By intention, therefore, their typical work lacks completely the simple ingenuous honesty of scientific text and technical report; it has none of that pellucid clarity which makes the expositions presented by diagram, theorem and formula so easy to understand. It is neither explicit nor precise: it is, by preference, allusive, impressionistic, cryptic; it is full of mystical potency; it smells of magic; and what is more significant, the more tantalizingly vague its thought appears, the more highly it seems to be esteemed among the cognoscenti. Finally and conclusively, it is shot through and through with cunning and indiscriminate appeals to spiritual, moral, and animal desires; and is generally characterized by an emotional self-indulgence of the enervating sort which, experience amply proves, is nothing less than fatal to good science and good sport.

Music, art and imaginative literature are thus judged by the people at large to be unscientific. That this judgment is merely discriminative and not in the least unfavorably prejudiced is evident enough. All men love tunes and pictures and stories — and magic too — of one sort or another, and usually prefer to be

intrigued rather than to be informed. It is only because literature and the arts are not didactic and genuinely instructive that they are accounted unscientific. Indeed, if further evidence were necessary of the ingenuous candor of popular opinion in this matter, this is provided by the fact that theology, which for hundreds of years was the one true Science, still retains among a restricted but growing congregation, and with common consent, this ancient title. Obviously, this is because its literature, the most imaginative and to the greater number of us the most poetic of all, remains, none the less, very satisfyingly explicit and informative.

All these evidences together provide us at length with a general definition of science: no arbitrary phrase, but a definition which, being derived from actual common usage, is at once dependable and illuminating. Any concern or occupation sufficiently important, purposive, practical, explicit and rational, which is based on knowledge or its pragmatic equivalent, is science. This knowledge (to avoid a fussy prolixity, let us call it that) may be the knowledge of natural phenomena either mechanical or vital, of emotion, will and thought, of human affairs; of ways and means, methods and procedures; of abstract relationships; of God. It is a very loose term, yet it has a sharply distinctive flavor: that of matter-of-factness and of detached rationality. This essence of the word, — to return to our useful ancient conception — thus clearly implies not so much a subject matter as an attitude of mind. And this attitude of mind, which begets a well-defined habit of thought, is that which is

characteristic of an easily recognizable human temperament.

In a famous passage, William James once distinguished two types of men whom he called the tough-minded and the tender-minded. Of these, the first comprises those who find their greatest satisfaction in the prosecution of affairs: industrial and commercial, political, ecclesiastic or scientific. The other type constitutes the bulk of humanity, who discover in emotional appreciations — crude or refined, ingenuous or subtle, commonplace or exalted — a greater joy than in the exercise of the practical reason. This type finds its extreme representatives among adventurers, journalists, artists and musicians, prophets, poets and religious devotees. It is also represented among the more severely intellectual, by the rationalistic metaphysicians, whose characteristic attitude of mind it is not difficult to derive from an essentially emotional evaluation of experience. The tough-minded sort are not only numerically inferior to these others, always; without being more highly individualized they are less gregarious, less spontaneous, sympathetic and mutually helpful, in short, more grown-up; and they are, furthermore, an instable variety which frequently reverts to type, and often very strangely, in a manner quite unfamiliar to the biologist: that is to say, temporarily. In other words, all humanity is tender-minded a part of the time; and this is a manifest blessing, since it is the only obvious justification we possess for our faith in human brotherhood. For these reasons, the very existence of the tough-minded type is precarious. If it were not for the persistence in

civilized society of a struggle for existence — which though it is somewhat perverted by the social habits of life which make cunning more effective than violence, is still but slightly abated and has forced the development of exceptional dynamic power among these men — they must without doubt have long ago died out. The history of civilization shows very clearly this tendency toward extinction. When the millenium which is pictured by the idealists actually arrives, they certainly will die out; but meanwhile they are society's strongest bulwark against degeneration and decay.

The pursuits of these tough-minded people are various and conflicting. In the past they have recognized among themselves no very warm and intimate consanguinity; many of the most bitter struggles which have marked the spiritual progress of mankind have been fought out inevitably among them, and their occasional coöperation has been and still is in large measure merely opportune; but with the slow maturing of their characteristic habit of thought, they seem at length to have recognized in it a common possession: the habit of devotion to and propitiation of "the God of Things as They Are." This habit provokes the investigation of facts alone and compels an ever increasing development of rational acumen and unemotional detachment. The knowledge which it yields, rid of all its accidental characters, is now commonly called science; and whatever seems to partake of its quality is called scientific. Even when these words are used carelessly or in error, they signify the belief or pretension that whatever is thus designated is, in fact, the outcome of rational and dispassionate investigation.

But it is not the outcome alone, not the accumulated knowledge and this merely, which is science. It will have been already observed that in common speech science means not only knowledge, but practice, method, technique, skill. In these significations we perceive the result of an association of ideas essentially different from that which leads to the former and more common usage. The accumulated results of tough-minded labor are science, certainly; but the labor itself is also science. To the onlooker, science is knowledge; to the worker, it is activity. Seen from the outside, it is something acquired; seen from the inside, it is the process of acquisition. The world at large is interested in the results alone, but the participator is interested also in the procedures. To borrow the imagery of our fellow-sportsman — the spectators see the game, but the players live it; the spectators know about the game, but the players *are* the game. Thus, in common usage the word has two meanings which express these opposite points of view — meanings very significantly different, though ordinarily they are synonomously interwoven and distinguishable only as varying emphases. Their contrast is that of product and process; outcome and procedure; effect and action; final cause and efficient cause: or, with further implication, substance and function; actuality and potentiality. Science is not only a great body of knowledge: it is also the activity which has produced and is producing this knowledge. And it is more significantly activity than knowledge; for knowledge itself is not merely a possession useful for the gratification of common human needs and desires, it is also an instrument for

the acquisition of new knowledge. The results of one scientific activity provide the methods of another. In science, therefore, as in common life, it is the function of knowledge which is important. None but the poet or the mystic is content to be enthralled by the mere contemplation of the marvels of nature. To all the rest of us, the great adventure is not so much the joy of understanding as the excitement of endless search; and correspondingly, to science the wonder of knowledge is not the richness of its present revelation but the limitless possibilities of its self-fertilizing growth.

These inferences summarize with sufficient clearness the most general implications of popular usage with respect to this word of many meanings. All these meanings, however diverse they may appear, are quite evidently very closely related by the connotation of an easily definable attitude of mind and habit of thought and action. But common thought has not merely thus exhibited an instinctive discernment which compels our puzzled admiration; it has also given evidence of a seeming aptitude for still closer discrimination, which is equally significant, inasmuch as it leads us directly to a sharp and final definition. This aptitude is revealed as if whimsically in the popular connotation, not of the word *science*, but of the word *scientist*. In common speech, all tough-minded people (or better, perhaps, all people when they are tough-minded) are scientific; but not all, certainly, are scientists. This designation is reserved for those who make the search for new knowledge not only their business, loosely speaking, but strictly their profession, and very often

their sole preoccupation. The tremendous majority of tough-minded people, even in their severest matter-of-fact detachment, do not philosophize very much about methods and procedures, and do not care at all about whys and wherefores: they want results. Any man of affairs will confess this with some pride; certain ecclesiastics are bold enough to do the same, and politicians act accordingly without thinking at all. To these men, consequently, science is knowledge merely; specifically, the knowledge which is power; knowledge for use; knowledge to be applied to the solution of a bewildering variety of problems, all of which are incidental to the prosecution of some purpose usually not scientific. Ordinarily this purpose is the attainment of wealth; frequently it is the establishment of an industry, or a state, or a creed; or the building of schools, hospitals, parks, prisons — and scientific institutions.

These are the men who are the actual builders, that is to say, not the laborers, but the designers, contractors, executive officers and managing directors of the enormous plant we call our civilization. It is they who have created at least its superstructure, magnificent or terrible, as you choose; and it must be admitted that it is they who keep it running: they are its bulwark, as has been said. In their presence all other men — their assistants, ministers, secretaries and servants — are dwarfed in stature. In the great drama of the world's work, they commonly pass unnoticed; and yet from among them the keen eye of the people singles out, as objects of a particular curiosity, a small group, the most reticent and inconspicuous of any, and calls them

scientists. These, in common opinion, are the toughest-minded, or better, the hardest-minded men of all; the pure breed, out of which the others seem to have been hybridized: pure scientists, in short. They are really no harder-minded than many of the rest; but in the imaginative view of tender-minded people they appear, when at their best or worst, to be positively adamantine: the aboriginal type, the real thing. In their normal condition — that is to say when working out their chosen problems, and therefore when not reverted, as has been explained — these men are exceptionally objective, detached, imperturbable, coldly and even recklessly rational; and their judgments appear to be even more cold-blooded than those of the executives who impatiently oversee their labors, wholly unaffected by any emotional evaluations whatever — such as good or bad, reassuring or terrifying, vivid or dull, beautiful or ugly, sacred or profane. But their distinguishing characteristic, that which sets them apart from all other hard-minds, is that they are equally indifferent to that evaluation which is the very basis of most tough-minded judgment. Not only is it all one to them whether the facts which they discover are pleasant, beautiful, beneficial or not. They even do not care whether they are useful or not. This is, of course, in the judgment of their practical hybrid cousins, a thoroughly reprehensible if not actually a criminal propensity. In an artist or some such other harmless visionary it might in charity be excused as a natural though exasperating weakness; but in a responsible tough-mind it is abnormal and shocking. And they would not tolerate it for a moment except-

ing that, after centuries of experience, they have at last discovered the astonishing fact (and facts are the things which count) that the best way to find new useful knowledge is not to search for this unrecognizable thing, but to take a chance; to follow, however reluctantly, the painfully inefficient example of nature herself, and to sow many seeds and lay many eggs, and leave it for luck to determine what shall survive and be brought forth: corn, perhaps, or weeds, or fungi; hens, or butterflies, or vipers. Thus the scientist not only survives but flourishes; and goes his imperturbable way, a privileged person.

The discovery of this pure strain among the mixed hordes of the tough-minded, which appears at first sight, and especially to its object, a rather startling evidence of intelligent and discriminating interest among the people at large, is really nothing of the sort. Even if one assumed, against the evidence, that the habit of careful inductive inference is a common trait, it seems unlikely that such discovery could ever have resulted from the extensive comparison of studious observations. Tender-minded people are so unsympathetic toward tough-mindedness that the task might well have been too uninteresting or disagreeable ever to have been carried out, even if it had been idly attempted. The true reason is as illuminating as it is evident. The quality by which the pure scientist is distinguishable — his indifference to practical affairs, his complete absorption in the eager examination of every queer and puzzling thing which comes to his attention — this is so striking, that he stands out among his fellows like a gull among crows — or, if you

prefer, a crow among swans — and compels notice. It is thus that he has caught the startled attention of ordinary men, and has at once become an object of intense and sympathetic interest; for in those qualities which so sharply distinguish him they recognize immediately a common possession: one of the primitive passions of humanity, a passion repressed or stultified by those who have become the slaves or victims of practical affairs, and ignored by professors of morals, but felt and recognized by unspoiled children of nature everywhere as one of the most powerful of human motives, as potent today as when in the Beginning it stirred in the breast of Eve — the passion of curiosity.

This recognition deprives all former preconceptions of the greater part of their significance; for it reveals the fact that the tough-mindedness of the scientist is not an original but an acquired trait. It brings him hesitant, somewhat uneasy and fearful, yet defenceless, back into the fold of the tender-minded, once and for all reclaimed as a genuinely normal human being. To sympathetic humanity, this is very gratifying knowledge. Auspicious in itself, it encourages extravagant hope. Impulsively, they even dare to suspect that if this hardest-headed man of all is merely one who masquerades like a sheep in wolf's clothing, then perhaps — it may be — even his powerful and recalcitrant brethren, our makers of destiny themselves, may likewise be stripped of their fearsome disguise and similarly gathered in. One cannot be sure, of course, and yet the inner conviction cannot be repressed that their case is similar. This is an agreeable

conviction, one of the sort that quickly transforms itself into belief; and a plausible hypothesis forthwith suggests itself. All people are tender-minded some of the time, their larger number a greater part of the time, many all the time; this is their common nature, and in this their brotherhood, which is real, consists. The peculiar instability of the whole tough-minded species, their tendency to revert, is thus made explicable. They are not a true species really, nor even a subvariety. Their characteristic traits are merely adaptations: functional responses to environmental conditions, like the growth of thick fur in winter. The whole train of thought is very suggestive: it leads to an envisagement of human life which, oddly enough, is peculiarly scientific. Beneath the impressive and confusing complications of our lives, it reveals the play of elementary impulses and emotions; and permits us to see, more clearly than we usually do see, in our industry, art, science, philosophy and religion, expressions of the primitive instincts to hoard and build and order somebody else about, to chatter, to play and to have thrills, to wonder and find out, to dream and yearn and pretend; and in our intricate affairs, likewise, only a variety of ingenious means for satisfying these desires without getting too much in one another's way. It penetrates much deeper: discovers the nature of reason in its function, puts logic in its proper place — and provides a natural background for the scientist. We may now really understand this man. He is merely one whose curiosity is overdeveloped and somewhat indurated by age and experience. His science, then, is whatever develops

from the curiosity of the child; which, intensified by fertile imagination, and disciplined by bafflement and error, has become in the mature man a still impulsive but a laborious and cautious habit of investigation, the solitary motive of which remains, very simply, the desire and the purpose thoroughly to understand, really to know his world.

This purpose, like every other which is insistent and compelling, develops in the scientist exceptional obstinacy, persistence, self-command and defensive imperturbability. It is these qualities, variously stimulated but similarly acquired, which produce tough-mindedness wherever it is found. They express merely the will to achieve. In the most ordinary of human affairs a degree of objective detachment is often attained which would easily match that of the most austere of scientific occupations. In trade, in politics and especially in the conduct of large affairs of any sort, men acquire as a necessary condition for the attainment of practical ends a habit of self-repression and uncompromising rationality, which seems to the uninformed observer, at times, positively inhuman. When faced with serious social responsibility or confronted by the critical emergencies of natural calamity, the most unlikely people often rise heroically to the heights of effective impersonal detachment. And no one is colder than the creative artist, when actually he labors. These are commonplace observations: their present bearing is obvious; for they reveal the fact that tough-mindedness is a trait which anybody might at any time acquire. It is completely accidental; in no wise determined by any particular predisposition, but

only by intensity of purpose and effort, under the spur of necessity.

This becomes vividly apparent if we compare our tough-minded people, not as heretofore with respect to their habits of action, but with respect to their motives and interests. The scientist and the man of affairs coöperate and almost understand each other, act alike and even come to look alike, for both work under stress and thus develop similar habitual traits: but their fundamental desires and purposes are as far apart as those of the mystic are apart from both. The working temper of the scientist and that of the man of affairs are very much the same, their methods in many instances are not unlike and are frequently exchanged; but the man of scientific interest who shares the motives of the man of affairs is not properly speaking a scientist at all, but rather a technologist. The scientist, excepting in so far as he is compelled by circumstance reluctantly to earn his living or dutifully to sacrifice himself in social service, shares none of these men's purposes; and their enthusiasms leave him cold, or even bored. Though his methods and procedures like theirs are practical, his compelling interests are nothing of the sort: they are, on the contrary, completely immaterial; very closely akin to those of the scholar or the reflective theologian whose spiritual ancestors were in fact his own. Precisely, they are those of the philosopher: his solitary purpose is to know; his only passion is that of discovery.

This passion is as old as humanity, or at least as old as society. It arose from unconscious or half-conscious adaptation to changing environments, and enjoyed

its first triumphs in primitive industry. In search for the control of mysterious and fearsome natural forces it begot magic and spell and prayer, leaping in the dark. Then, having discovered ghosts, it conceived the gods, who remained for countless ages very satisfying indeed to all mankind. They still suffice for the majority of us, but certain prayers they will not answer: and there has come into the world a type of man — he first appeared in Ionia something over twenty-five centuries ago — who is nervous, impatient and dissatisfied with their mysteries; who prefers the light of day to the shrouded gloom of the cave. This man, while usually prudent enough still to propitiate the gods, has, nevertheless, gone elsewhere in search of knowledge and has learned to question not the oracle but the face of nature. His way has been rough: he has guessed and imagined in vain, or almost in vain, his impatience and enthusiasm have betrayed him again and again, and throughout the ages he has had to endure the fear and enmity of most of his kind, whose comfortable group thought he has too harshly criticized. But at length, after weary years, he has learned humility and patience and endurance; has been forced by repeated failure to curb his imagination, and to test his guesses endlessly by the facts brought to light in experiences both old and new; has discovered ingenious ways of prying into dark corners and of revealing new mysteries while destroying the old; until now, although he knows that he has merely begun his search, he is able to demonstrate new magic in the market place, and thus to convince his fellow men — all but the poets — that

his way to knowledge is the surest and best that man has tried, and that he holds in his hand the key to further human progress, if only humanity is wise enough to turn it the right way.

Something of all this the ordinary man feels when he thinks of science; and henceforth a new significance attaches to the word. The science which is knowledge is knowledge of a superior quality, the result of an arduous and disciplined experience, of persistent and methodical effort, tested and retested time and again by the reluctant revelations of nature, and proven against the prejudices of men and gods by conflict, martyrdom, and final persuasion; a knowledge, therefore, which probably is more precise, more accurate and more dependable than any other. And this is not all. It is knowledge which is not only more exact and dependable but immensely more extensive and minute. It actually includes the whole of common knowledge in so far as this is verifiable, excepting only those isolated scraps of experience which have no definable relation to the bulk of it and hence are of no practical value. Common knowledge is, in fact, nothing else than the raw material which, assorted, refined and chemically transmuted, has served as the basic substance of its vastly elaborated synthesis. Or better, it is only the original germ which, incubated and nourished by careful hands, has now become a mature and self-sustaining organism intricately yet economically built, and almost perfectly coördinated in function. For this knowledge, despite its incomprehensible bulk and seemingly endless detail, is more perfectly classified than the simplest and most meager of any common

lore, and is bound together and interconnected by a system of actual and theoretical relationships which gives it not only a unitary structure, but also that internally responsive adjustment of activity which ensures both present efficiency and future wholesome growth. Without metaphor, it is organized knowledge; and not this only: it is also living, growing knowledge and preëminently, fertile knowledge.

This marvelous product of man's unrestricted, impersonal, most practical and least utilitarian thought has placed in human hands the greatest power they have ever wielded. Its potentiality for good or ill is immeasurable. And because of this, it has been granted in modern times the highest authority over the thoughts and acts of men — those of primitive desire and will alone excepted. Its theoretical correlations, built to serve the needs of research alone, are popularly (and often philosophically) interpreted as dogmas; its exclusively instrumental methods and results have already become outside the walls of its own laboratories the basis of a new religion. To the majority among those who question the authority of mere tradition, our scientific representations conform completely to the accepted standard of gravest judgment: that is, — with the most serious implication of ordinary speech, — they tell the truth, the whole truth and nothing but the truth.

An examination of this common belief will simultaneously serve two useful purposes: first, it will define the primary character of the scientific synthesis; second, and derivately, it will exhibit its precise relation to contrasting or conflicting habits of thought

and doctrine. The question as to how nearly science comes to telling the whole truth cannot be profitably discussed before the basic principles of its philosophy have been outlined. There are, however, the best of reasons for believing that science tells the truth and nothing but the truth.

A tentatively favorable judgment to this effect is defensible on historical grounds alone. It is, however, confirmed by the most convincing of all possible evidence: the repeated fulfilment of bold predictions, which has led by a mulitiplicity of discoveries confidently anticipated to an assured control over natural agencies effective beyond the wildest dreams of poets and seers. This evidence does more than establish a probability. It substantiates with seeming conclusiveness all the generalizations of fact and all the theoretical inferences derived from them upon which prediction has been based, and by implication gives authoritative weight to all accepted scientific doctrines of similar character. The force of this evidence upon common judgment is now so great that it usually compels incautious and even credulous assent to any assertion or expression of opinion which may plausibly claim a scientific sanction. But whenever this is not the case, then, unless the actual procedures which have led to prediction and discovery can be traced in detail, there must always remain the possibility of legitimate doubt concerning it. True conclusions which have been derived by erratic reasoning from false premises are as familiar to the artisan as to the logician; and knowledge accidentally acquired but falsely presented as the product of supernormal in-

telligence is all too familiar to an ingenuous and heartlessly exploited humanity. The very wealth of successful scientific predictions, to be sure, provides cumulative evidence which makes such error or deception in this case most unlikely, and this supports belief; yet it is clear that the detection of a single fallacious inference fortuitously confirmed, or of a single false pretension apparently verified, must dangerously undermine whatever confidence is placed in any probability. The skeptical mind, therefore, demands further assurance, both as to the validity of the methods of science and as to the sincerity of its declarations.

This assurance the scientific record provides. It stands always open: no books are sealed. No sacred treasures of esoteric knowledge are any longer paraded in the custody of saturnine and portentous guardians. Within the temples of modern science no potent arcana lie hidden; listening at their portals, one hears the echo of no incantations. And in the open record no mystic symbols adorn the written page, no cryptic allegories obscure the meaning of its sentences, and no statements require elucidation on the part of any supernaturally inspired person, or demand acceptance on his authority. There is, in short, no hocus-pocus in this literature. Its language at times is strange enough, and its diagrams and ichnolitic shorthand are puzzling enough to engender such suspicion; but these are all more or less explained in little books which are insistently advertised and distributed in quite unnecessary profusion. The record is one of minute details: of countless experiments which may be at any time re-

peated, of calculations which may be checked, of inferences which may be analyzed and criticized on the basis of the facts presented. It is a record of both truth and error; but one which has been so many times corrected and amended that the error which may still remain unrecognized or unspecified is such as will probably require the discovery of new facts for its detection. Any one who has sufficient knowledge and aptitude can read this record, and, if he has access to the necessary instruments and material, can verify its statements of fact. It is true that no individual ability is great enough, and no single life is long enough, to make it possible for one man to read and understand it all, much less to verify it all. But whatever part of it may be thus examined — with or without reference to the wealth of minutely critical and controversial matter which it already embodies — it will be found that all of its ultimate conclusions are justified by observations many times confirmed, and by reasonings logically validated.

The mere existence of such a record as this is sufficient to allay the doubts of the great majority of skeptics. Its very character stamps it as trustworthy; for it gives fullest evidence not only of a free, disinterested and unrestricted spirit of inquiry, but of inquiry conducted under conditions exceptionally favorable to unprejudiced investigation. It describes the work of men who have labored either alone or in voluntary or accidental collaboration, usually brief. This work has never, excepting accidentally, served the purposes of any human organization whatever; it has contributed nothing, excepting accidentally, to the satisfaction of

group desires; and if it could be controlled by power for such purpose, it would at the worst be suppressed or destroyed, and not perverted, for the whole value of its findings lies in their consistence with fact, which no man determines. It is, furthermore, the work of rivals. In this, as in every other field of endeavor, there are weaklings who might serve ambition by dishonesty, a greater number who might advertise themselves by sensational clamor, a multitude who, unadvised, might venture incautious and hazardous judgments through eager impatience for fame: but in this work such means are futile and worse; for these men are always before the bar of their peers, every one of whom may gain some distinction for himself by exposing or correcting them. In a similar way, the recklessness of youth is tamed by the heavy, deliberate caution of age, and the dogmatism of age exposed by the skeptical alertness of youth. In this work as in every other, the fortunes of the individual may be advanced by favor or arrested by stupidity or jealousy, and thus nepotism or vanity may retard its advance; inevitably also, the influence of greater men may overdevelop or check particular phases of its progress by the weight of temporary authority; but these and like effects are always transient, for no reputation can long be maintained excepting by significant achievement, and the greatest opportunity of each scientific generation is the overturn of old authority by the discovery of new facts. Such is the working of rivalry in science: inevitably it yields the truth; just as in commerce, though far less certainly, it brings low prices.

These, then, are the conditions which have ensured among scientific men in the past the persistence of that disinterestedness in the search for truth which their native curiosity engenders and their failures compel. The progress of science is like that of a self-purifying stream: automatically it destroys pollution, and feeds our reservoirs of wisdom — and of folly — with uncontaminated knowledge. It fertilizes and enriches the plantations of mankind, and has not yet been seized and diverted from its normal course by any single aggressive group. It turns the wheels of industry but has not yet on this account run dry in its natural bed. The power of its flood has been utilized ingeniously in a thousand ways, though not yet with adequate intelligence.

The questions which such reflections suggest are of the greatest social importance. Before they can be profitably discussed, however, it will be necessary to examine somewhat more minutely the nature of scientific reasoning, the philosophical basis of its scheme of representation, and the authority of its pronouncements. And further inquiry of this character is necessary in any case, since without it anything more than a very superficial understanding either of science itself, or of any aspect of its cultural relations would be quite impossible.

It will not waste time, at this point, to summarize briefly the results of the informal discussion just concluded. It has been made clear by the more obvious

implications of ordinary usage that science in the most general signification of the term means any purposive, practical, explicit and rational concern or occupation which is based on positive knowledge or what passes for such; that the word connotes no particular subject matter, but rather an attitude of mind, and that this attitude finds expression in a certain well-defined habit of thought and action which is single-minded, matter-of-fact and methodical — and, in its higher development, cold and detached, severely rational and constructively but never emotionally imaginative. This habit is known to be characteristic of an easily recognized human temperament which has been happily designated the tough-minded. It is that of men who appear to find their greatest satisfaction not in the indulgence of their emotions or aspirations but in the prosecution of affairs. This temperament, however, it is necessary to observe, is not a native character but an acquired and even accidental trait. It does not, in fact, afford the slightest clue to the motives of that man who is commonly designated a scientist in the narrower meaning of the term. This man is distinguishable from all others in that his single passion is the gratification of curiosity. His work is therefore conducted not only without reference to any emotional evaluations whatever, but in complete indifference even to the criterion of usefulness; and he is thus to be sharply differentiated from all other tough-minds, whose motives, speaking generally, are definitely utilitarian. To these men the scientist actually appears whimsical and wasteful; but his results are occasionally very useful, and since no way can be

devised of foretelling which of his discoveries will prove to be available in affairs, his efforts are reluctantly encouraged and promoted. By his single-mindedness in the search for new knowledge and by his indifference to the practical results of his work, that is, by his motive, the scientist allies himself with the philosopher and the scholar rather than with the man of affairs; but by his method, which has been learned in the rough school of arduous experience, he is more closely in accord with the practical man. His work is thus unique; and it is invaluable, both because his methods embody the most refined and effective procedures of all practical intelligence, and because his results, obtained under conditions which ensure the elimination of deceit and group control, supply humanity with its most extensive and minutely elaborated, most highly organized and most thoroughly dependable knowledge. His methods and his results are both science; and his work cannot be properly understood by the examination of either alone. It is a living activity and must be consistently treated as such in all discussion.

It is quite obvious that any adequate exposition of scientific methods and results must be somewhat critically analytical; but this need not imply that it must also be rigidly logical or subtle or exhaustive, to serve the purposes of preliminary inquiry. A thoroughgoing examination of the philosophy of science, obviously, would demand not only a minute familiar-

ity with scientific methods and procedures but a clear understanding of all the implicit presuppositions which they involve; and such knowledge is yielded only by a protracted and intensive study of the subject. This philosophy, like every other, is retrospective: it exhibits not the common processes but the final results of scientific reflection, and cannot, therefore, be clearly understood in advance. With reference to common knowledge alone, however, it is possible to describe these processes, to depict accordingly the general character of scientific reasoning, and thus by simple inference to exhibit its more striking contrasts with other habits of thought; to indicate if not to discuss the more insistent questions which are either answered or evaded by its philosophical postulates, and to define the legitimate range of its authority, thus predetermined. The conclusions arrived at in such preliminary study will be of course only roughly expressible, but will not on this account be at all misleading, since even if they need subsequently to be formulated with greater exactness, they will meanwhile define unambiguously the scientific attitude of mind, and will thus provide a point of view from which scientific problems properly so-called may be clearly distinguished from others with which they are commonly confused, so that all later scientific criticism may easily be disencumbered of irrelevant considerations and gratuitous misconceptions. The advantage which is secured in any general discussion by a tentative prior definition of purpose, attitude and method is peculiarly valuable in the study of science, since for reasons easily discoverable, though not immediately

apparent, there is no type of intellectual activity which is more commonly misinterpreted.

The best summary characterization of the scientific habit of thought is that of Huxley's famous definition. "Science," he wrote, "is . . . nothing but trained and organized common sense." The value of any aphorism of this sort of course lies wholly in its connotation. The particular value of this frequently repeated utterance is not only that it appeals sharply and specifically to a conception which is commonly entertained and well understood, but that among all of its possible implications there is none which, properly interpreted, is significantly misleading. This is because it is the definition not of a lexicographer, or of a professional philosopher, but of a scientific investigator and critic of method whose attitude and opinions were representative of the most competent scientific thought in the most productive period of scientific activity, and whose influence on the subsequent progress of science has been profound and lasting. It characterizes science from the point of view of the worker who criticizes his results in the light of an intimate acquaintance with their genesis; and presents it, therefore, not as knowledge alone nor as systematic doctrine, but as maturing opinion, the product of a particular habit of thought. In a discursive manner, and somewhat loosely from another point of view, this habit of thought has already been discussed. The definition here quoted may be accepted, therefore, as a happy summary of conclusions already reached, and in a general way its implications will be grasped at once. A more particular examina-

tion of them will define the scientific position exactly.

By 'common sense' we mean *the understanding of man in action.* The designation itself has its origin in the fact that this understanding is common to all men; that is to say, it comprises the usual representations of normal human intelligence. It is our purposive understanding. Under the influence of love or fear or other emotional exhilaration, and in reflective or imaginative or self-conscious moods, we live in worlds which are frequently too dissimilar to compare, and the fixed ideas which these moods may generate quite usually determine the direction of our efforts; but in the actual working out of our will and desire — while we are *doing* anything — we all think alike and our thought is common sense. In meditation we may live in whatever philosophical realm we choose, but in action we always return to the world which common sense describes. This is our common immediate world, the world in which we desire and strive and die. It may be but an aspect of some greater imaginable world — which, it is worth remarking, must contain it all or be incredible — but if so, it is the only aspect of any such world with which we are compelled to deal, however far beyond it we may dream. It is the world of Necessity: the primary complex of which we discover ourselves to be a part, within which common sense has been developed in man out of his instinct of self-preservation. Our actual existence in this immediate world depends upon a process of adaptation to circumstances and occurrences external to and independent of ourselves; and this adaptation has been suc-

cessful in just that degree to which the changes which take place in our environment have been closely observed, compared, and in some measure classified, and their recurrences and interrelations to some extent understood, so that events could be anticipated and actions predetermined to cope with threatened danger or to seize promised advantage. Common sense, then, is our inescapable common philosophy, which may be refined, interpreted and transcended to any degree in thought, but never, in its essentials, contradicted — since in its essentials it merely describes the crude experience which yields the primary data of all thought whatever, and in terms which that experience immediately determines.

These essentials of common sense are the general ideas which have been developed directly by man's vital needs, and have survived his age-long struggle of adaptation. They are, consequently, among all our numberless conceptions, those which have proved most useful as instruments of understanding and guides to effective action. In other words, they are our fundamental practical ideas: the basis of all the thought which may be involved, not only in any actual undertaking, but also in every immediate envisagement of that ever-changing totality of things-in-relation which we call the world of nature. Very slowly, by imperceptible degrees, the rigorous pragmatic test of living has separated these ideas from all others, and has given to common sense that quality of uncompromising matter-of-factness which now so sharply distinguishes it from purely speculative as well as from unrestricted imaginative and emotional

thought. This separation is probably the most significant result of our mental evolution thus far. In common habit it is not yet complete, and probably never will be; yet the process has already gone so far in the unconscious mind that it makes possible a very sharp dichotomy of experience which provides us with the most clarifying of all our basic conceptions: that, namely, of two separate but interacting worlds; the one a world of emotion, thought and will, the other a world of insensate matter and energy; a subjective world and an objective world.

This essentially practical division of our experience is now so natural to the majority of us that unless we deliberately reflect, we are apt to accept it as immediately given, to wonder that it should provoke comment, and probably to suspect the mental eccentricity of anyone who thinks it worth discussion. None the less, it must arrest the attention of the critic of common sense and of science, for it is the fundamental postulate of both: and if we are to understand either more than very superficially, we must realize that it is not by any means a primary datum of experience, but rather a working hypothesis; a habit of representation subconsciously developed by the exigencies of life, the significance of which is solely that it clarifies thought, and thus makes action more effective. It is very important that this fact should be grasped; for all the categories of common sense and of science are of similar derivation, and since in coördination they merely describe the detail of a universe thus conceived, they are all correspondingly provisional: representative rather than explanatory, furnishing us a picture

of nature which is in the highest degree convenient, but not necessarily in any ultimate sense real, excepting perhaps as an incomplete synthesis of selected relations.

The implications of this inference are so far-reaching, and with respect to the final import of scientific knowledge so illuminating, that it is worth while to examine somewhat minutely the evidence which supports them. This leads at once to the consideration of some of the most difficult and most important of all philosophical questions, those namely of epistemology: the theory of knowledge. It goes without saying that this is properly the business only of unusually acute and exceptionally trained minds. Necessity, however, ignores caution. It is only the angels, that know no necessity, who fear to tread such quicksands. And, after all, the philosopher invites us here: he has prepared the field — that part of it, at least, which it is profitable to examine superficially — especially for our clumsy exploration.

There are several standpoints from which it is possible to examine the process of knowing. Of these, the most promising of all is that of common sense; for this is not only the one universal attitude of mind, it is also the most ingenuous: closest to the primitive, whatever that may be, and most likely to yield us evidences of those relatively simple mental processes from which we may provisionally assume our present habits of thought to have been derived by refinement and complication. We have been well aware, ever since Aristotle pointed out the fact, that all of our particular critical habits of thought, whether philosophi-

cal or religious, are derived from those of common sense; for whatever may be the doctrinal presuppositions which define the character and tendency of the reasoning they embody, all of these are hypotheses or postulates which are necessarily stated either directly or by implication in the imagery of common experience, and every process of inference which they employ finds its exact parallel in the thought which accompanies action. This is merely to state the obvious, of course; and it is only because of our habitual carelessness in assuming without reflection that ways of knowing are essentially different that it needs to be noted. Schemes of thought are various; but the images and the processes of thought are alike. Our several systems of correlation present widely different pictures of the world, but all of these are painted with the same brush; and all, moreover, are interpretations of the vague outline sketch which common experience provides — like the imaginative products of children's play which make old men and elephants and birds out of single crooked lines. These ways of knowing — including that of matured common sense itself — are all attempts to transcend the knowledge of action. The epistemologist has undertaken the fascinating task of discerning in these elaborate drawings, if not the single crooked line from which all are derived, at least the simplest recognizable complex of scratches common to all, within which it lies concealed. Common sense presents the least elaborate of these pictures: it is therefore good method to choose it as the object of first analysis. We are sufficiently familiar with all of the completed pictures to anticipate that, this anal-

ysis having been carried as far as possible, the explanation of the rest will be a relatively easy task; for the points of divergence between our systems of religious and philosophical thought are matters of historical record and first-hand discussion.

So far as choice of method is concerned, such investigation presents no difficulties, since in the absence of all means of estimating in advance the plausibility of any hypothesis, it must be inductive. In actual living we commonly experience different degrees of awareness which merge into one another in various ways. These yield us the conception of a process, the process of knowing, which we may trace some distance back from the condition of its full maturity through stages of development successively more simple until the process of analysis is blocked by the insurmountable assumptions of our simplest thought. That is to say, from within our complicated world of common sense we may by familiar acts of memory bring together and compare what we call various states of mind, arrange them in an ascending order of complexity, and by noticing various phases of their interrelation describe the act of knowing as an evolutionary process. We cannot trace this process backward very far, but we can determine its trend and, as a physicist would say, extrapolate toward the origin. The hazards of such extrapolation are well understood. It serves at best to give us a system of coördinates. In common words, we find it impossible to describe the simplest or, in terms of our evolutionary idea, the primitive condition of awareness with reference to which we would like to describe and

coördinate the rest, or from which, assuming a process of development, we might derive them. But, in the process of analysis, we do find it possible to proceed surprisingly far: far enough to determine with considerable precision and in no little detail our habits of thinking, which we discover to be of a generally definable character; and far enough to put ourselves in possession, if not of crude experience unalloyed, at least of experiences so far removed from those of conscious ratiocination that we can at least get outside of these and study them, so to speak, objectively. We thus arrive at the immediate realization of a range of intensity in actual awareness, from the vague and confused to the vivid and clear, far wider than that of which we are commonly conscious. Among these states the most diffuse are sufficiently chaotic to be undescribable, and between these and definitely conscious conditions we discover a gradation which exhibits successive differentiae that may be roughly defined. The process of knowing having been thus determined it is, finally, possible to imagine the continuous simplification of the act and thus to arrive not at a conception of undifferentiated crude experience, but at a sort of apprehensive feeling toward it from the ground of the most diffuse of our actual experiences.

It will be noted that in this procedure, since the data are provided by an elaborated common sense, they all involve its categories: in other words, in this tracing back, we are forced to express ourselves in the terms of our actual common knowledge. We are, in fact, so far as actual knowing is concerned, completely im-

prisoned in this present world of action. Whenever we venture to delve beneath it our way is blocked as effectually as when we try to soar above it. In either attempt our thought is reduced to metaphor; the terms of our subtlest analysis and boldest synthesis alike are cast in the moulds of its imagery. This discovery alone would justify all the labor of all the philosophers; for it not only demonstrates the rigid limitations of knowledge, but defines them. Though we may not break through the walls of our prison, we may learn where and what these are. Thus, also, we realize as we might not otherwise, the hazardous character of our very analysis. Our method is primarily subjective, that is, restricted to one particular domain of our common sense experience; but the results sought are to be general — they must, therefore, be confirmed in our other, objective, domain before we can accept them; and our hypothesis of development must be similarly verified. This done, we may claim for them validity within the world of space, time and constraint, beyond which we cannot even guess. But, since our procedure itself is a process of knowing, the validity thus established will be nothing beyond that of a general consistency in thought. We are compelled to the belief that there exists no other demonstrable truth than this.

It will now be possible to summarize briefly and superficially without much danger of false implication, the simpler results of epistemological research which most directly concern the student of common sense and of science. If we are metaphysically inclined — if, in other words, we are impatient with partial syn-

thesis, and demand a solid rock on which to build, or a cosmic cloud from which to emerge, or some such other transcendental ultimate — then there is no harm in postulating, consistently with all the foregoing considerations taken together, a beginning of everything which we may call crude experience. This Origin is a something which is preferable to any other postulate as a starting point of scientific synthesis, inasmuch as it is derived directly from — or better, is indicated directly by — the backward extrapolation of that synthesis itself, and involves no other hypothesis than that the process of knowing is in some way continuous in actuality and potentiality. This crude experience cannot be defined, for definition is something which is assumed to have happened to it; it cannot be felt because likewise feeling has been differentiated out of it; it is neither spatial nor temporal, nor forceful: for space, time and energy are aspects of its assumed elaboration in actuality. It has, in short, no conceivable attribute: no character whatever. This is why science ignores its own ultimate origin — permits itself, in fact, to doubt whether the word origin has any but a relative meaning. It would be quite obviously purposeless to dwell any longer upon this puzzling question: it is worth while, however, to have been momentarily detained by it, since we thus catch glimpses simultaneously of a characteristic limitation of science and a wonder of metaphysics.

The beginning of knowledge, for science, then, lies within the field of actuality. It is that condition of awareness which we have called the most diffuse: a condition very frequently experienced, though seldom

noticed. It is revealed to us in moments of fatigue, or slow awakening, or drug-intoxication, or at will whenever the attention is unfocussed and we become as nearly as may be unselectively receptive to external influences of all sorts at once. We are then aware of a jumble and confusion of what we call, when we are awake and alert, sensations — intermingled, or rather undistinguished; not seemingly the parts of a whole, but the simultaneous and blended constituents of a wonderfully rich aliveness. That this is an immediate experience which is common to all men is indicated by the accord between diverse descriptions of it, by its uniform association with antecedent circumstances of like character, and by the similar actions which its modification or interruption provokes. A perfect blending of impressions is never experienced, but is approached only at the verge of unconsciousness. It is therefore impossible to say whether or not there is any completely undifferentiated experience, but of the generally vague experience there is no doubt, and all experience is partially vague — never clean cut but always, as in vision, fringed with confusion.

A different and sharply contrasting variety of experience yields further data respecting the raw material of knowledge. This is the experience of intense activity, during which we are more acutely discriminative than at any other time. In this experience among all others there is the least of vagueness: no blending of objects and sights and sounds or of feelings; but self-consciousness disappears completely. It is the two worlds of our retrospective common sense that now are blended, and this time indistinguishably.

In the consciousness of the actor, subject and object are one: he is the thing he does, with all that it involves; he is a sharp cross-section of total experience which traverses perpendicularly the plane of his habitual reflective division of it. The skilled player of any athletic game, no less than the soldier in action, knows this experience, and furthermore gives evidence of it to others; there is no experimental scientist who cannot recall the occasion when he was as much an external process, or a thermometer or a mathematical relation as anything else; the musician improvising hardly distinguishes himself from his instrument, or either from the flood of melody which engulfs them both.

The evidence which establishes the generality of these experiences is not only that of subjective acquaintance, agreement and consistent action: it is also that of historical record. Our separated worlds of matter and mind are a very recent acquisition of common sense. The conceptions of preanimistic religion and the lore of primitive magic are inexplicable in terms of modern common sense. Indeed, the whole complex of reflective savage thought implies a partial continuity of individual and social, subjective and objective experience. When we try to understand this thought, we are usually compelled to resort to the notion that uncivilized man habitually projects himself and his society into the outer world; not only ascribing to insensate things will and desire and the consciousness of duty, but subsequently imagining a participative sympathy, an intimate rapport between his mind and theirs. All this is gratuitous: it need not be as-

sumed that there is exhibited here any projection of the human mind into nature; one may more plausibly believe that it has not yet been sharply separated *from* nature. The thing felt or thought and the thing seen or done are of one whole world: the sympathy of social rite and private magic is that of a simple continuity of experience. These primitive correlations survive in various forms, as for instance, in the idea of luck; they are characteristic of mystical religion; they have been formalized in the doctrines of early philosophy and modern dogma. We may often say legitimately of these last that the replica of human consciousness has been projected into nature; but frequently it would be more plausible to assume that it has merely remained there.

Such is primitive experience so far as we know it. In gross outline, the manner in which it is elaborated is commonly understood. The rich confusion of our most diffuse awareness is suddenly inundated or gradually overflowed by a vivid, obliterating newness which is everywhere the same: a roar, a flame, a shock, a rapid motion. It may subside: but if it persists, and above all, if it recurs, we awake and attend. Attention thus in a thousand ways, and in actual experience very rapidly and even simultaneously, separates and divides the drowsy confusion into noises and lights and odors and pressures, cold and warmth and pain. These persist or recur, and with recurrence they take on form, locality and intensity and become defined as things, or as occurrences in time. Experience multiplies itself by division, with increasing sharpness and minuteness. We observe: localize, temporalize, dis-

criminate, and discover sameness, persistent or recurrent, in one place or many. Then we compare: and from discrimination pass to differentiation. This is the beginning of classification; and this now goes on very rapidly, yielding, in an increasing profusion of separate experiences of things and processes, the first glimpses of order. We begin to notice, in the moment when we first vividly realize that no things and processes are exactly alike, persistent groupings of differentiating attributes, and of differences of behavior; discover genera, characteristic properties, types of process. Perception imperceptibly passes into conception: we have ideas, and with ideas, knowledge.

All this experience now arranges itself in a complicated general picture which, from the moment it is first outlined, continually persists: we remember. And in every stage of memory we recollect, and repeat the process of comparison and classification with the images of this recollection. These may be more easily handled than the vivid experiences which they reflect, we may do with them what we will; and so we imagine, and guess at new and perhaps more useful correlations of experience than those which were first spontaneously made. We thus begin to criticize our experience, to have theories. We do this because all this time we are living and wish to make the best of it. Of course, it is a pleasure to imagine, particularly since by doing so we can partly satisfy our too frequently baffled desires by gratifying them in this shadowy realm of obedient images; and we do this habitually. This commonest imaginative activity, to be sure, has nothing to do with common sense; the less

extravagant reconstructions of memory, however, our guesses, are of the highest practical value. They are valuable for two reasons: first, because by correlating wide ranges of experience which exhibit no apparent continuity, they make thinking easier; second, because in their tentative application to labor they encourage the development of the most precious of all habits, the habit of experimentation. This in turn reveals new knowledge, which prompts new guessing — and the ensuing recurrent series of thoughts and acts is the very essence of what we call the development of culture or, with respect to knowledge alone, the progress of science.

This fragmentary and superficial survey, like every such effort, yields little specific information; but no general summary would do much more, unless it were a critical treatise. It is the trend of development alone which can safely be generalized; and even this is questionable with reference to any sharply distinguished sequence of its phases. With respect to contemporaneous thought alone there is, in the absence of sufficiently inclusive data, quite enough uncertainty; and one is not justified, in view of the complexity of the phenomena, even to insist on a general uniformity of process. With respect to any less developed thought — which means in this case prehistoric thought — we are, of course, forced to be almost wholly hypothetical: such evidence as exists, however, supports the natural presupposition of its essential conformity. Any attempt to fill in the gaping chasms of implication which are so airily bridged by the cautious terminology of such a sketch as this will give

point to these qualifying remarks. It will, however, clearly reveal the exceptional richness of the field of research, as well as the extraordinary difficulty of the problems it involves, and also the almost overwhelming force of the inferences upon which the synthesis is based.

It is these which determine the scientific attitude of mind. They are: first, that all thought whatever is derived from some phase of common sense, the understanding of man in action; second, that thus far every attempt to transcend the world of experience which common sense describes has met with failure, that all the thought which such attempts involve is couched necessarily in the imagery of these experiences, and that no system of religion or philosophy can do more in an intellectual way, therefore, than to elaborate diverse schemes of its conceptual coördination; third, that among these schemes, that of matured common sense itself alone is possibly descriptive of every phase of experience, since from the manner of its development it alone serves the necessities of actual living, and since for reasons already assigned all other schemes of correlation must be stated in its terms; fourth, that since the relatively undifferentiated complex of diffuse awareness is that from which all postulated ultimates spring by the imaginatively metaphorical development of some aspect of its common-sense elaboration, this is the only possible basis for any intellectual synthesis, whatever the will may demand or require; fifth, that if the intellect itself demands an ultimate, the conception of crude experience will best meet its needs; but sixth, that this conception like every other

which is transcendent of actuality is quite unthinkable, and therefore negligible; and seventh, that consequently the ultimate has no legitimate place in knowledge, whatever may be its function in hope and faith; so that, whatever belief may postulate concerning it, in science, phenomena, which may be interpreted as its actual manifestation, alone have place. It follows, eighthly, and penultimately, that there is no absolute knowledge properly so called; that all scientific truth is relative, its only criterion being general consistency of experience; and that since experience grows, this truth is also tentative and provisional, never final. Ninthly, and lastly, there follows an important corollary: that for identical reasons all of the preceding conclusions are likewise provisional; which makes the scientific attitude in generality, as well as in detail, one of completely suspended though obviously active judgment.

But furthermore — postfinally, if one dares to be ultralogical — another corollary may without harm be stated: that the whole of the preceding exposition must be considered tentative, since it cannot be presumed to be based on an exhaustive analysis of scientific opinion, and has not been subjected to more than partial verification. It should also be acknowledged that its wholly satisfactory verification would be rather difficult. The natural scientist is not given to logical criticism; and it must be confessed that he rarely considers the fundamental presuppositions of his thought. Quite commonly he is conscious, in the prosecution of his work, of no other guidance than that of previously tested procedures and correlations. In ordi-

nary practice these work quite as well as more critical thought would work, and have the advantage of not distracting the attention. It is only when the frontiers of knowledge in unfamiliar fields are first explored and when customary methods and theories begin to lead him astray that he has to make original thinking a part of research, and even then he can stagger on surprisingly far, though laden with heavy burdens of false reasoning. For it is a part of scientific experience that correlations once useful remain so in some degree even after their inconsistency with new experiences, that is, their falsity, is quite apparent. A wrong theory is frequently better than none, so long as the gravest issues remain uninvolved. The tested routine of science is not, to be sure, as efficacious as Lord Bacon imagined it would be; and his ideal institution in which the obscurest depths of knowledge were to be fathomed by the coöperative labor of morons is not yet perfected. None the less, it is no more necessary that every scientist should be an original thinker than that every executive should be so. This is one of the reasons why research is so productive. In this, as in every other field of labor (excepting perhaps philosophy) the bulk of the work is done by those who in the workshop follow the rules, and elsewhere are simple believers or atheists, communists or Fascisti, husbands or golfers. The scientific rules are not only eminently workable; like all good tools which serve common purposes, they have been built to withstand rough usage and to be of passable service even in the performance of tasks for which they were not designed. They commonly last a lifetime or longer, and in the

ordinary scientific household do not need even to be sharpened.

On the other hand, the men who originally formulated these rules, and amended or altered them at one time or another, very often knew exactly what they were about; and whenever this appeared to be even doubtful, they were almost always enlightened by the philosophers, and not infrequently discussed the matter, sometimes vigorously and at length. From sources of information thus provided, it is possible to draw plausible inferences concerning the premises of argument, even though these be not explicitly stated. The rules themselves, however, and particularly the history of their changes and amendments, provide a richer and more diversified mass of evidence, which is also more dependable, since it is the evidence of behavior. All of these indications point to the gradual historical development and final definite maturation among scientific men theoretically disposed of the definite convictions above formulated. There are relatively few among them who explicitly state these opinions; but all theoretical scientific thought appears to have this trend; and when its statements seem to differ from those here set down, it is usually quite clear either that the criticism back of it is incomplete, or that the final step in its formal development has been inhibited by the irrelevant and alogical interposition of traditional dogma.

It will be useful to give this group of tentative doctrines its proper name. It is a well recognized philosophical attitude of ancient and highly honorable lineage, which traces its descent from Carneades and

Aenesidemus to Hume and to James and Dewey. Because of its refusal to admit the existence of ultimate knowledge it is naturally condemned by the theologian, though sympathetically tolerated by the religious mystic; and for the same reason, though it is accorded the dignity of a school of thought by all philosophers, its distinctive criticisms are met, among the metaphysicians, by an unpremeditated but effectual conspiracy of silence. It is the school of Skeptical Empiricism and its criteria of method and judgment are those of Pragmatism.

The immediate connotations of the three words empiricism, pragmatism and skepticism define the philosophical position of the scientist sufficiently well for all but dialectical purposes. Empiricism means that habit of thought, or any doctrine it may formulate, which derives all knowledge from experience. This type of philosophy, because it restricts the field of knowledge to the actual, and consequently fails to give the support of reason to the most compelling of all our hopes and aspirations, is commonly misunderstood, and is frequently misrepresented even by professional philosophers. It represents a mental attitude and habit of thought which is not only unacceptable but is often acutely antipathetic to the idealistic mind; and is consistently opposed, not only by the tender-minded, who misinterpret and consequently fear its teaching, but also and particularly by all those earnest and uncompromising thinkers whose insistent and unnatural

purpose is to intellectualize and formulate our instinctive religious and moral emotions.

Now, ever since the period of the Greek enlightenment, philosophers of this idealistic persuasion have dominated all Western speculative thought; and as a natural result it has come about that even in common speech the word empirical has acquired, by the contagion of reiterated suggestions, something of the meaning which their instinctive and unreasoned hostility has assigned it. In ordinary usage, consequently, the word now frequently suggests a plodding, short-sighted, rule-of-thumb philosophy — an earth-bound philosophy of labor, ignorant of and uninspired by the larger vision which is granted the intellect in its untramelled higher flight. This insidious suggestion finds expression even in the terminology of science itself: in medicine, the designation empiric, as everybody knows, has become a title of derogation; in theoretical science, we are all familiar with what we call empirical equations, which summarize the obscure relationships between phenomena which we cannot generalize and thus clearly understand. All such secondary implications of these words are nothing more than the vestiges of ancient philosophical prejudice: pitiful evidences of the intolerance which is characteristic even of our most high-minded idealism. They must be quite disregarded, and if possible completely ignored by any student who wishes honestly to understand what scientific empiricism really means. The empirical philosophy arose, not through ignorance of the higher flights of the philosophical intellect, but on the contrary as a direct consequence of the

keenest and most searching criticism to which they have ever been subjected. The history of this criticism has not yet received from reluctant philosophers the attention which it must receive before the record shall be justly balanced, and the scientists have been too preoccupied to repair this error of neglect. It is to be hoped that we shall not be compelled to wait much longer for the appearance of an unbiassed exposition which shall clear our minds of the emotional disturbances that have thus been allowed to persist.

Meanwhile, however, it is not impossible for anyone to judge the empirical position quite impartially, if he merely keeps the scientific purpose clearly in mind. This purpose is exclusively the attainment of dependable knowledge. The scientist, as a scientist, is interested in nothing else. As a human being, he shares the common hopes and aspirations which find their almost universal expression in systems of belief: religious, ethical, or philosophical. In his chosen labor, however, he is, or attempts to be, completely and unequivocally rational; and this makes him an empiricist. It is worth repeating that he has made it his business to learn as much as is humanly possible concerning real existence, that is, the existence which comprehends not the world of ideas alone, but the complete world of thought and action at once; and that since ideas present themselves in thought, it is necessary for him to test them in action before he may accept them as universally true. This makes consistency in thought and action, which is to say consistency in experience as a whole, the sole criterion of truth; and experience, therefore, the source of all knowledge.

Clearly then, it is not because he ignores the flights of the philosophical imagination that the scientist is empirical; he is empirical only because he is consistently rational, and will not, for this reason, permit himself to accept as truth any idea, however intense its emotional appeal may be, however inspiring it may be, unless it conforms to his criterion; nor to accept as a methodological postulate any idea which, though it be true in the sense that it cannot be disproved, is nevertheless infertile — that is, useless for the acquisition of further knowledge. The scientist has never, excepting when he has himself been affected by the influence of extraneous dogma, shut his eyes to any possible opportunities in the search for universal truth. Metaphysics has offered him many suggestions, and there is probably no one of these which he has not candidly and carefully examined, and at one time or another tried out in practice. Of these suggestions, many have been found to be contradictory of fact and therefore false; others plausible, but sterile and therefore unavailable; others, again, constructive, and often remarkably fertile. His fault in the eyes of the transcendentalists is not really that he ignorantly despises their subtle thought; this is only the cry of wounded sensibility. Their protest is, rather, that he has dragged down inspiring ideas to the level of brutish facts, has judged the aristocracy of mind in the common court of vulgar sense, has sacrificed the higher in our nature to the lower. From the point of view of the scientist, this accusation, though understandable, is quite unjust. In his severer mood, indeed, he would call it irrelevant, if not meaningless; for if we dis-

regard poetic metaphor, there is no higher or lower in human knowledge, unless perchance we prosily refer to geographical altitudes. Ideas are more or less general, more or less fertile or otherwise consequential; but there is no aristocracy or hierarchy of ideas: such notions are not originally philosophical, but are, rather, moral or aesthetic. In its aspect as knowledge, all experience is one.

The philosophy of empiricism assumes many forms which differ not only in detail of representation, but also, and more significantly, in method. Among these, scientific empiricism distinguishes itself by accepting as its primary datum, not the elements of experience which are the terms of matured reflection, but the whole vague complex of diffuse awareness. It thus avoids many problems of extreme difficulty which are involved in the attempt to synthesize in thought a complex of separate existences assumed to be primary, since by its own premise these are derivative, and the problem of their obscure relation one merely of increasingly minute description. In one sense, therefore, it appears less to avoid than to evade a number of traditional problems which to many remain insistent. By its own criteria of judgment, however, it is quite as legitimate to solve a problem by analysis as by synthesis, since according to these criteria no postulate has any compelling authority, but is merely a point of view, and the solution of any problem is nothing more than the establishment of intelligible general consistency: an explanation being not a revelation, but a progressive elucidation which is nothing else than more and more precise and general-

ized description. The solution of these problems, therefore, is quite properly the endless business of research.

This acceptance of the whole experience at once as primary datum makes scientific empiricism equivalent to what James called radical empiricism; the method here indicated makes it pragmatic empiricism. Pragmatism means, most broadly speaking, the acceptance as truth of all generally consistent statements of relation in the description of experience. Now, since experience is not postulated by science to be indubitably ultimate, this truth is not considered absolute, but relative. Since, also, experience is continually being elaborated, it is not fixed but changing; and is therefore, in any particular aspect, tentative. Furthermore, it is never certain, but at best probable; because there is no factual relation which is completely defined and consequently not open to reinterpretation, and also because it is conceivable that the elaboration of diffuse experience which has actually yielded these relations might have been, and may yet be, otherwise conducted and thus produce new truth which is preferable. The basis of such preference will always be superior consistency: and since nothing more than a narrowly limited consistency is ever demonstrated by a comparison of ideas alone, appeal must always be made to the world of events to establish any truth.

It is therefore clear that in the pragmatic view an idea is true in so far as, and so long as, it works. This commonest expression of the pragmatic attitude is often absurdly misunderstood. It does not mean that because an idea is useful, or personally acceptable,

consoling or gratifying, it is by that token true. The workability of an idea, before it may be held to establish its truth, must be demonstrated in every sort of experience to which the idea is applicable. This does not mean, of course, that the idea need be positively informative over the whole range of such experience. Its practicability may be sharply restricted, and it may yet be considered true so long as it introduces no inconsistency into the general scheme of thought. But even when such inconsistency is demonstrable, it does not necessarily yield proof of falsity; for it may not be an inconsistency of idea with fact, but an inconsistency of different schemes of representation merely, both of which are workable in their particular ranges of applicability excepting where these overlap. In this case, it would quite obviously be foolish to reject either idea as false, since new knowledge might at any time prove one of them, and perhaps both of them, after suitable modification, to be completely consistent with fact. It is therefore more reasonable to accept them meanwhile as imperfectly — that is in some sense, or incompletely — true. Such truth is merely provisional, of course; but this appears to be the general character of all our ideas, even of those which are considered the most dependable. We like to think of truth as final and absolute: but scientific experience convinces us that if we insist on giving truth this meaning, then it is highly probable that the word must actually be eliminated from the scientific vocabulary. Our thought might, indeed, be considerably clarified if this were done; but for the sake of avoiding the gratuitous burden of a technical philosophical diction in scientific writing — which is

by necessity sufficiently technical already — it is more practical to redefine truth than to use artificial words or cumbrous phrases to take its place.

To proceed: an idea which is generally inconsistent with experience and therefore fails to work, is false. But it may also happen that an idea is inapplicable in action: in this case it is, to the pragmatist, neither true nor false, but negligible. And finally, it may happen, and has happened more than once in scientific experience, that two opposed representations applicable to the same set of relations are equally consistent, after their implications have been extensively developed. In this case, either may be considered true, for the time being; and if for practical reasons a choice must be made between them, it will be made wholly on grounds of expediency. The usual choice in such emergency is the simpler idea, since this serves economy of thought. There is an old philosophical adage to the effect that hypotheses are not to be multiplied. It was derived from a former belief that nature is essentially simple; and this belief had its origin, doubtless, in an unconscious pragmatic choice of this sort. At a venture (not unsupported by historical evidence), the prior dilemma, that of two contrary and equally credible ideas, is what most insistently called for the definite formulation of this pragmatic attitude.

In the thought associated with action, this attitude, of course, is instinctive. If it appears strange to us in reflection, or even repellent as is too frequently the case, then the source of our difficulty will be at once apparent if we substitute for the word truth the word

probability. For ages, the idea of truth in common thought has been that of something absolute and final, and usually divine. It has been the goal of our highest intellectual aspirations: to be content with less, is difficult. But science has at length been forced into this position. There has probably been no idea of final truth that has not at one time or another been tried out as the basis of her synthesis of experience: but all without exception have been found to be either inapplicable to experience or inconsistent with some phase of it. To retain useless ideas would have meant to carry a wholly unnecessary burden; to cling to false ones would have meant to be led astray.

It is to be remembered that the consistent description of all experience, the task that science assigns herself, is, if it be not accepted as the final goal of intellection, an essential step in the construction of any general metaphysic. In other words, a metaphysic inconsistent with any phase of experience is false. In assuming the pragmatic attitude, the scientist is merely taking a step which is necessary to avoid continual blundering in his attempt to solve the most immediate problems in philosophy. He concedes the possibility that his synthesis may not be final, though he insists that it is logically prior to and completely involved in the construction of any higher metaphysic; that it is, in short, the necessary basis of all metaphysics in so far as this is rational; and that therefore, from the philosophical as well as from the practical point of view, it is necessary that the greatest possible care be taken to ensure its general consistency. The pragmatic attitude, thus explained, will be generally con-

ceded to be reasonable and wise. The common prejudice against it is explicable not only as an expression of our almost universal impatience to solve at once and out of hand the profoundest problems of cognition, but also as the result of general misinterpretation of the scientific purpose, which it must be admitted the advocates of free thought, in the intensity of a bitter struggle against group prepossessions which has lasted for centuries, have done little to correct.

Our desire for an immediate solution of ultimate problems is not a childish weakness but an inescapable predisposition. The psychologist now recognizes that one of the two or three primary human instincts — those which appear to involve no process of inference — is the fear which is occasioned by loss of bodily support. This same fear operates intellectually: we demand first of all security in our convictions; after that, if we are courageous, we may venture to criticize them. It is easy to see that all the prejudice which operates to retard the progress of free inquiry, whether it be religious, moral, economic and political, or purely intellectual, may be largely thus accounted for; and it is likewise evident that among all of these prejudices there is none more powerful than that of intellectual conviction.

The suspended judgment which the pragmatic attitude demands, and which is the very essence of scientific thought, is consequently one which is acquired with great difficulty and is seldom sustained beyond the range of restricted fields of thought. If the philosophical purpose of scientific research here summarily defined be kept constantly in view, it ought not to be

difficult for anybody to appreciate the value of pragmatic method within the scientific domain, although the necessity which has compelled its extensive employment is not likely to be realized by any but those who have had a considerable scientific experience.

It will be realized, if this purpose be clearly apprehended, that the pragmatic conception of truth is primarily a methodological postulate; and even if the philosophical development of the idea be rejected, the scientific attitude itself need not, on this account, be unsympathetically viewed, nor an understanding of scientific methods essentially impaired. The greater number of scientific men, even the greater number of those among them who are critically disposed, are, as has been previously implied, averse to philosophical pragmatism, though every one of them is a thoroughgoing pragmatist in his strictly scientific thought and labor. It is worthy of remark that, from the pragmatic point of view itself, opinions are indifferent which do not significantly modify behavior: those, therefore, which do not affect scientific procedure are by this token extra-scientific and, with respect to this field of activity, indifferent.

All the more compelling of our intellectual convictions are of this character. As distinct from our less certain but practically useful opinions, and correspondingly, as distinct from our scientific theories, they are embodied in what we call our metaphysical beliefs — or more precisely our theologies, for seldom if ever is there any real distinction between the two. It is these beliefs which satisfy our instinctive craving for certainties. They summarize and give meanings to

our habitual envisagements of the world as a whole, such as may be determined either by the common thought of our social group or by the tenor of our individual preoccupations. They thus possess for each of us an authority which is derived, not primarily from the intellect, but from a more potent source: the will, usually unconscious, to justify to our critical understanding the most insistent of our desires and aspirations. This justification, in the mind of the metaphysician or theologian, is fully accomplished if the representations and evaluations of experience which his dogmas embody are not inconsistent with common experience; and a large variety of comprehensive doctrines, even when they are mutually contradictory, easily satisfy this condition. On account of their very generality they cannot be made explicit in terms of particular experiences — cannot be measured and numbered — and thus made susceptible to scientific test. This being so, they may without harm be accepted as individual convictions by any who do not demand of them a meaning very precise. When thus accepted they still our intellectual unrest and preserve meanwhile something of that primitive thrill in the face of Mystery, something of that hypnotic dread of the Unknown which the profoundest knowledge never can dispel nor do more, indeed, than reduce to awe. Their affective and therefore their moral value to humanity is consequently profound: a fact which the simplest mind intuitively recognizes. And any one of them, or all of them at once, may possibly be true in an absolute sense; may adumbrate, so to say, some aspect of final truth: we cannot tell. But because we cannot

tell — because we cannot give them precise definition in terms of fact and thus drag them down into the realm of verifiability — they are of negligible significance in the field of scientific investigation. This is what is meant by calling them pragmatically — that is to say, scientifically — neither true nor false, but indifferent; or, if one prefers, irrelevant.

All this leads to, and indeed implies, Skepticism. It needs to be remarked, before any attempt is made to explain this aspect of scientific thought, that the skepticism here referred to is a highly cultivated philosophical growth: not the common or garden variety, which so easily runs wild, and induces among us all quite indiscriminately the intermittent hay-fever of disgusted exasperation. Nor is it the serious religious skepticism which attempts the rational undermining of belief. Philosophical skepticism appertains exclusively to the theory of knowledge, and does not touch religion at all excepting — as will be explained — on the intellectual, which is to say, the theological side, where indeed its findings are in essential accord with those of the great scholastics. This skepticism, then, means much more than the simple infection of doubt; it is not a destructive philosophy of negation, as is so frequently asserted, but rather a methodical discipline of tentative judgment — explicitly, the philosophy of caution.

Scientifically, skepticism is the negative aspect of empiricism and pragmatism. Not only does science adopt consistency as the criterion of truth: within her own domain she excludes all other conceptions of truth. That of transcendental truth is ignored, nec-

essarily, for it is found to be beyond the range of actual experience. Within that range science also refuses acceptance to any truth derived exclusively from authority. A full description of authority, of the searching sort to which science is accustomed, identifies it roughly as merely the domination of habit, and usually of a habit the grip of which is due to strong emotion which is derived from personal need and desire or from a comforting sense of security; which, though it is frequently supported by argument, is not originally a product of thought but rather one of will; and which is frequently so powerful in its opposition to free inquiry that it inhibits certain tendencies of thought altogether, so that when it is not actually subversive of reason, it introduces into the intellectual life quite arbitrarily the most glaring inconsistencies of opinion. Science has learned, through error, that the most destructive influence within her domain is emotional bias of any sort. When this is directly productive of inconsistencies of representation, its exclusion obviously becomes a necessity. None the less, an idea supported by authority is not to be on that account alone rejected: such rejection itself would be emotional judgment. It follows, therefore, that in science, authority must be merely ignored, and the ideas it enforces subjected with complete equanimity to the usual pragmatic tests. Adjudged to be only the pretension of habit, it may be either good, bad, or indifferent — or, in pragmatic terms, constructive, destructive or gratuitous.

The exclusion from science of transcendental and authoritative doctrines alike means that in scientific

thought no dogma whatever, whether mystical or metaphysical, theological or moral, is permissible. It is thus only that science ensures its cogency and freedom of thought. The exclusion of transcendental irrelevancies, which assists towards the attainment of its logical purpose, is a methodical procedure which has never occasioned serious dispute. The question of its freedom of thought, however, has been fought out in the bitterest, most cruel and most protracted struggle that the human spirit has ever undergone; and this is a fact which it is wise to remember. The victory has been won and the issue is closed. It is well to bind up all wounds and allow them to heal; but it is disingenuous, and weakly if not dangerously sentimental, to pretend that the conflict was without deep significance.

The force of habitual prejudice upon the individual mind has just been commented upon: the effect of such prejudice upon action is still more powerful, for in action the fear which determines their intensity is reinforced by the blind primitive desire which is never wholly absent from human will, to dominate and command. This desire is strong enough and ugly enough even in its commonplace manifestations: with respect to the gravest of human concerns, those namely of belief, it frequently becomes an insensate and unscrupulous madness, and provokes acts which in the whole range of criminality are the most damnable. When such feeling becomes a group prepossession, its fury is unrestrained; and since in its conceptual aspect it may mask itself as a lofty ideal, it may generate even among the gentle and humane, and most dangerously

among those who are intellectually keen and persuasive, a stern and inflexible purpose which rejects no instrument of coercion to remould all mankind into semblance of the image it creates.

This is the force against which science has contended in the past. The age-long conflict has been no sad misunderstanding, as timid altruists would have us believe, but war: a fight for life or death; and the revolution which the victory of science has at length concluded, that which for the time being has made intellectual toleration dominant in the world, is the most momentous that history records. There is no need to dwell upon its consequences, which are apparent enough in every phase of recent social progress. Man is now in a position through the unrestricted development of his equable pragmatic thought to control his destiny: and his emancipation from the grip of the primitive brute impulses which for hundreds of thousands of years have controlled him, is nothing else than the product of that God-given spark of skepticism which curiosity has kept alight in his soul. It is just as well that the tender-minded be asked to remember these things; especially in those moments when the damped but unquenched fires of atavistic fervor which are always smouldering underground, occasionally burst forth to threaten new conflagration.

Considerations of this sort are apt to make the ordinary man, despite instinctive distaste, feel more kindly toward pragmatic skepticism. In this mood he

will be more inclined to consider dispassionately the consequences of its further philosophical development. He will realize clearly, to begin with, that customary modes of thought, when they dominate a man's most serious purposes, are very apt to extend their influence beyond their original confines. That is to say, the scientist's habituation to pragmatic and philosophically skeptical thought in his laboratory and study is very likely to make him thus practical and skeptical about everything. Indeed it is somewhat remarkable that so few scientific men are radically skeptical in religion, morals and politics: this is one of the most vivid illustrations that can be called to mind of the extraordinary inertia of earlier acquired habit, which has been so aptly called the fly-wheel of society. The phenomenon is still more striking to one who recalls the fact that the one irresistible passion of the scientist is curiosity. It would naturally be supposed that a man whose greatest delight is to peer and pry, and whose eternally haunting fear is that he has made a mistake in observation or judgment (particularly a man who has actually professionalized both instincts) would be unable to rest before he had applied his microscope and his syllogism to every puzzling aspect of his experience. But, as everybody knows, it is not so at all. The only possible explanation is that he is already sufficiently puzzled by the problems he has first sought to solve, and has become over-busy and preoccupied. None the less, it sometimes happens that he does grant himself the leisure to think seriously of other matters; and then it is that the scientist becomes a skeptical empiricist in the full meaning of the term: a kind of

philosopher in short; though usually, not having studied philosophy with sufficient interest to learn very much about it, he would probably deny this.

It would lead too far afield to discuss at any length the attitude of this philosopher. It is worth while, however, to glimpse the tendency of his thought, since for reasons which will soon be apparent if they are not so already, this will afford a clue to the probable future influence of science on general schemes of conception. For present purposes it will be sufficient to develop a little further the implications of two facts already noted. According to the pragmatic criterion of judgment all transcendental conceptions are scientifically indifferent, and, for reasons which are obvious, they must always remain so. Now, this by no means implies that even to the scientist himself they are without value; for to be useless in a scientific sense and to be without value are obviously two entirely different things: a sharp reasoner might prove the contrary, but we could circumvent him by arguing that there are many values which are not scientifically explicable — as yet. Well, then: this makes it clear that to any scientific mind transcendental metaphysical systems may have all the value which appertains to the greatest works of art. They are, in fact, great poems, the most magnificent that the human mind has ever conceived, lacking only music and warmth to make them superior to the greatest epics — which themselves derive their grandeur, if they possess it, from their quasi-metaphysical content. They are, in a word, the most imaginative of all human productions.

But the scientist in whom the skeptical habit is most

thoroughly ingrained — that is, the most liberal scientist — will concede much more than this to such metaphysics. These great works all attempt the transcendence of the immediate world of common sense; and this, science, on the basis of cumulative historical evidence and epistemological theory, believes to be impossible. By her own criteria of judgment, however, it is quite unjustifiable to be dogmatic about this: every scientific conclusion is tentative, and subject to revision. It is not at all impossible that metaphysics may yet grasp some principle now transcendent and drag it down into the world of verifiability. The mathematical physicists already seem on the point of doing something like this, and though they appear to be a little precipitate in their enthusiastic prognostications, one cannot be sure. Indeed, analogous things have taken place before. The boundaries of scientifically verifiable knowledge, that is to say the boundaries of the world of common sense, are, like its internal content, changing: the term transcendent, therefore, like every other term, has only a provisional meaning. It is consequently difficult to distinguish this metaphysics from science: much that is now science was once such metaphysics. This is strikingly evident in retrospect; and an examination of the historical record yields still more. Not all of metaphysics is transcendental. Originally it was the knowledge of first principles, or, as the scientist would now phrase it, of most inclusive generalizations; and this meaning still survives as the best — the one we have been employing being derivative and of a character which has been determined by the close historical association of

instrumental logic, mathematics and physico-biological science, and their rather recent separation from speculative philosophy. Now, the historian of science, on the basis of his record, is compelled to admit that, whereas the sharpest and most useful primary concepts of science have been inferred directly from experience, her broadest generalizations, those which supply the great framework of her conceptual structure, have all without exception been supplied her, not always as vague suggestions but in more than one instance as matured theories, by speculative philosophy. His record tells a similar tale with respect to method. Speculative philosophy is the mother of theoretical science: the fact cannot be controverted by the most obstinately myopic of progressive thinkers. Stated otherwise, scientific theory is philosophic theory which has survived the pragmatic test. All of which is in the nature of things, and would hardly justify remark excepting for the prevalence in common thought of contrary impressions based on misinformation.

There are, then, no inevitable conflicts between science and philosophy, excepting such as frequently rage within each of these now distinct but closely related brotherhoods. One group appeals to intuition and its logic, another to facts; one criticizes the value of this logic, another asks the definition of fact; and thus it goes, as in every other not too well regulated family, where wounded feelings are healed by the consciousness of sympathetic motives, and compromise is effected by mutual education.

There is one sort of philosopher, however, who

usually stands apart during all these loud-voiced but ultimately harmless wrangles: he is that member of the composite family who is destined for the church. His aloofness is not primarily due to his better breeding: his equability of manner, indeed, is quite misleading, for no human being is more in earnest. He palely loiters amid the turmoil only because he is mildly entertained; for seriously, he considers it all to be arrant nonsense. This man is the mystic; whose thought deliberately rejects the criterion of consistency to which all his brothers and cousins appeal, either logically or pragmatically. He is the most tremendous skeptic of all, for he discards as philosophically worthless the last remaining postulate of the intellect. This is not to say that he is consistently unrational; none of us is ever wholly consistent. He eats and clothes himself, gets out of the way of automobiles, and takes a passing interest in reasonable discussion. But his heart is not in these things; and he permits the not unamiable laugh at his expense with complete good nature, because he considers the whole illusory business to be of no real consequence. He lives mentally in another world altogether, an unimaginable world of sweetness and light and glory which none of the rest of us attain.

The attitude of the scientist toward this philosopher reveals his characteristic temper anew and in a particularly interesting way, inasmuch as it illustrates very clearly and explains quite unequivocally his habitual attitude toward religion: a matter of common concern and frequent misrepresentation. The essence of mysticism is religious emotion; and this universal

and most compelling but unreasoned experience, as has been already fully explained, now lies wholly outside the domain of strictly scientific interest. It does not, however, lie outside the more inclusive domain of philosophic interest, and through philosophy, in the first instance, it touches science; for the mystic, whose dogmas, if he entertains them, are elements of belief which in his case are not fundamental but secondary, is in the habit of justifying his attitude philosophically. He thus confronts the scientist not with conflicting theories concerning the world of nature, which are the primary cause of all uncompromising opposition between scientific and religious thought, but with an alternative theory of knowledge — an entirely different matter, and one which he is accustomed to discuss with an equability which matches that of the scientist himself. Since also, the mystic represents — so far as any type of thinker may be said to represent — the mental attitude which is common to all religious men, unobscured by the accidental influences of particular and conflicting doctrines, it results that a comparison of the premises of his thought with those of the scientist is the best way by far of approaching the candid consideration of a vital human problem which is commonly and quite unnecessarily feared and evaded in amicable discussion.

The philosophy of mysticism is historically derived from and remains at present based upon a categorical denial, as frequently asserted as it is implied, of the possibility of attaining final truth by the exercise of reason. It is, therefore, essentially an extreme dog-

matic skepticism which differs from scientific skepticism only in that scientific skepticism is more thoroughly consistent. In common thought, the similarity of the philosophical premises of science and of mysticism usually escapes attention: and if it is remarked, the distinction between these premises, which is equally important, is seldom grasped. It is worth while, therefore, for the benefit of those who have not given this matter the serious attention it deserves, to describe briefly both the likeness and the contrast of these two attitudes of mind. Both the scientist and the mystic, as a consequence of the age-long failure of the metaphysicians — in the beginning as a consequence of the failure of Aristotle — to demonstrate rationally the nature of final truth, and as a consequence also of an appreciative study of the characteristic limitations of our powers of inference, have concluded that any attempt to understand the ultimate nature of things is likely to be profitless. Thus far they agree: but then immediately they disagree, and their disagreement reflects directly their contrasting temperamental predispositions.

The scientist, still curious, intensely interested in this present world and not too much concerned about any other, clings tenaciously to his common-sense — that is to say, to his rational — habits of thought, which even though they may merely elaborate a distorted vision, continue nevertheless to serve him well in all practical affairs, and promise to yield him at length a consistent picture of the world as satisfactory to him as any other type of revelation, or illusion, might be to another. He does not, meanwhile, com-

pletely relinquish his hope of final understanding; for, he argues, if reason be fallacious in one respect, it may be equally fallacious in another. Specifically, it is quite as likely that his skeptical opinion respecting the possibility of grasping final truth may be wrong, as that any other of his inferences may be wrong. His picture of the world may, for instance, be merely incomplete, not necessarily false. Its still rational reinterpretation through knowledge yet to be acquired, may imaginably permit, if not the immediate realization of final truth, then successive approaches toward this realization — perhaps endlessly, perhaps not. This is not belief, of course, nor even expectation; but it cannot be denied as possibility by any consistent skeptic. Since the scientist chooses to be rational, therefore, he is compelled to doubt his very doubt. This makes him a complete skeptic whose final judgment in all matters whatever is suspended, and renders his philosophical position unassailable.

The mystic, on the other hand, having been convinced of the likelihood that reason is wholly impotent in the face of eternal mystery, is overwhelmed by this realization. Unlike the scientist, he is meditative rather than curious; as a philosopher he is not much interested in this present world, and under the influence of that discouragement which all men share who soberly reflect upon their own mortality and that of those they love, or upon the injustice and cruelty of man, or the ruthless processes of nature which are the causes of these and all other sufferings, he reaches forth with irresistible yearning toward another world where restless and tortured souls may at last find

peace. Philosophy thus far has satisfied none of his more compelling hopes and desires; and he becomes as other men more simple, whose will must always dominate their thought. That the intellect serves our practical need most admirably is obvious enough; but it serves our deeper and more insistent longings very ill. Only to the insensitive or to the abnormally curious, and seldom if ever to any but the healthy and fortunate, does it suffice. When, therefore, we discover that it mocks our dearest hopes — away with it! Let it serve our passing necessities, briefly, pitiably. The mystic has no quarrel with common sense nor with science; but what, he asks, is the good of all this arduous labor, which satisfies our gross desires but starves our souls? Philosophically it leads nowhere:

> "Myself when young did eagerly frequent
> Doctor and saint and heard great argument
> About it and about, but evermore
> Came out by that same door wherein I went."

In this mood the mystic is no longer critical. His skepticism becomes destructive; for hope too long deferred has made him sick at heart, and emotion more profound than any that the scientist experiences renders impossible for him the patience which acceptance of a thoroughly inconclusive skepticism would demand. He *will* have final knowledge. Reason will not grant it, and even though consistent doubt admits its possibility, this possibility admittedly is remote. He will listen no longer, therefore, to the cajolery of reason, which feeds his dying hope with empty subtleties of thought, denying him all assurance and demanding that he endure still more. His skepticism,

then, becomes absolute: he rejects altogether the authority of reason.

The philosophical position which the mystic then assumes is in a sense even rationally unassailable, for with the dethronement of reason its last criterion of judgment, consistency itself, has no force in argument. The mystic may thus justify himself even to the scientist; for if one is by choice unrational, he may permit his skepticism without fear of adverse criticism to be dogmatic. If, therefore, the mystic may negligently acquiesce in the rational conclusions of the scientist within his own domain, the scientist in his turn must admit with equal *sang froid* the competence of the mystic as a metaphysician, and his perfect right, even by rational standards of judgment, to seek transcendent knowledge, if he choose, by extra-rational means.

This search, of course, is the mystic's earnest purpose. No more than any other man — much less, indeed, than any other man — is he likely to rest content with a philosophy of nescience. But beyond reason there is no other way to knowledge save that which leads by passive receptivity to immediate revelation. The mystic, then, by means which are as various as the human habits and predispositions from which they are derived — through purification, meditation or ecstacy — seeks to establish within himself a condition which will put his soul in resonance with the soul of the universe, the existence of which he apprehends by intuition. This done, he participates in the universal essence and has knowledge of ultimate truth. No representation of mystical motives and practices, couched thus in common phrase, could pos-

sibly convey more than the vaguest impression of the mystical frame of mind. The scientist, however sympathetic he may be, cannot imagine it, for its mood is beyond all common experience and reason. There is no man, however, who has not at one time or another had the rare moment of emotional exaltation and instantaneous vision, the persistence of which might make him understand it. These flashes of inexpressible emotion, universally experienced, are in themselves sufficient to make the whole world vaguely mystical; to confirm all religious beliefs; to make scientific skepticism itself, occasionally, somewhat more than skeptical of its doubt.

Of course, in its habitual work-a-day mood, science turns the searchlight of its intrusive curiosity even upon experiences such as these; and no man can justify any interference with this sort of investigation, for, whatever ultimate significance these emotions may possess, they are, in the natural world, psychological phenomena, and as such are science's legitimate concern. To many it is still difficult to concede this right; and such reluctance is understandable, for here the intellect trespasses upon the forbidden ground of the sacred. The right is granted, however, by the mystic himself, who in this matter at least sets us all an example in toleration. To him, since rational thought is impotent to deal with any experiences excepting those illusions of sense which are called phenomena, it could not, if it would, affect the sacred. Moreover, he is fully aware that human emotions are treacherous: it is difficult, sometimes, to distinguish a revelation from mere imagining; and the receptive,

to whom alone true revelation can be granted, are always the easiest victims of deceit. That final truth may be revealed to those who sincerely seek it and are strong enough to make the necessary sacrifice of ephemeral earthly joy, he is convinced; for even though he fail himself, there is evidence which nearly all the world accepts that it has been thus revealed to others in the past. Let science then discover what it can about the quicksands of emotion through which the path toward revelation leads, that their dangers may be avoided. It is only natural that we put ourselves on guard to protect the sacred; but our fear that common thought can touch it is itself an illusion. Today instinctively and fearfully we guard the spirit against imagined injury; yesterday with even sterner obstinacy we guarded the body which is its dwelling place, and before this, during ages of fear still more intense, we guarded with savage cruelty mere social habits and conventions: all because, emotionally unreasoning, we feared their violation, and thus made them taboo or falsely sacred. Now science, having analyzed these fears, has shown us, not only that they are groundless, but that in yielding to them we have multiplied our miseries. We study social habits now as phenomena no longer charged with dread, and thus learn how wisely to adjust and control them to our betterment; we study the human body, no longer untouchable or inviolate in death, and rid ourselves of countless maladies which we had long imagined to be the visitations of divine wrath; and this scientific probing of the mind, against which we still instinctively revolt, is already yielding knowledge which

promises to release us from the haunting fears that yet remain.

Scientific investigation thus serves religion as it serves philosophy. It is permissible for the mystic to consider it an instrument of purification. By identifying in human experience all that which is undoubtedly phenomenal, it permits the increasing clarity of vision which reveals an actual in place of a doubtful realm of eternally persistent mystery; a realm into which it never intrudes, where conjecture and faith alone dare venture. What matters it, then, that the scientist is skeptical about this overworld? The very thoroughness of his doctrine of doubt refuses him the privilege of denying the mystic's faith, if such were his unrational desire. He may say that no reason supports this faith, but the mystic, and even the dogmatic theologian himself, says the same thing. The prosy matter-of-factness of the scientist may shock our sensibilities; but to tolerate this offense is surely a very small price to pay for the inestimable service which he has rendered us.

What, then, is the cause of the conflict between science and religion: the bitterest and most uncompromising of all human conflicts, considerably abated now but by no means stilled, and under favorable circumstances (which are not in the least improbable) likely at any time to be violently renewed? The question may be briefly answered, for it presents no difficulties whatever to any understanding. The religious emotion unalloyed by doctrinal belief is a common possession of all humanity; and the temperamental antagonism between men who evaluate it differently

is for this reason very seldom intense. It is commonly no more difficult for the devout to tolerate the scientific mood than it is for the artistic or the literary or the utilitarian to do so, or for the scientist to tolerate aesthetic vagaries, or romanticism, or self-important efficiency. Humanity has at last become sufficiently mature, in the absence of specific oppositions of purpose and will, to tolerate divergences of opinion respecting values; and in this, as in all other wholly personal disagreement, is willing to live and let live.

There is then no unavoidable conflict between religion, thus conceived, and science; no serious issues which arise from temperamental antagonism alone. The great conflicts of the past have always been, as those of the future will probably always be, the conflicts between fixed and unreconcilable beliefs; and never between beliefs concerning a transcendent mystery, excepting when these have become entangled with contradictory opinions concerning our actual world. These opinions themselves, more frequently than not, have been advanced as the justification of more primitive motives — the fear of change in custom, blind loyalty to ancient institutions, the lust of power either petty or grandiose; and the bitterest of all this warfare has been waged in the defence of individual freedom against aggressions thus incited. They have been battles of will, primarily; instigated by fear, desire, ambition, or greed, supported when they have not been provoked by the power of group obsessions, and never directed by intellectual or religious purposes excepting when thought has been enslaved by the strong emotion which is generated by these

primitive impulses. To call such warfare the conflict of science and religion is essentially to misrepresent it: it is rather the warfare between humane intelligence and the brute will to dominate and command, excited or sustained by group prepossessions. Its issue is not between religion and science, but between oppression and toleration. Yet there persists in this warfare, beneath these elemental and sufficient causes of strife, a concurrent conflict of beliefs which survives the triumph of either oppression or toleration and even outlasts the bitter feeling which physical struggle engenders. It is a conflict of ideas; and as such may properly be discussed without reference to the conflict of will with which it is entangled.

In the life we call primitive, all thought which concerns the welfare of the group, especially the thought which accompanies concerted action, reflects the defensive habits of tribal life which like experiences and common necessities make fairly uniform, and itself tends to become uniform. Egoistic jealousy also, which in all stages of culture is the popular expression of either tyrannical or democratic self-respect, works to the same effect through intimidation and violence. And more significantly, the limited knowledge of primitive peoples — which restricts their inductive thought and conceptual imagery to very narrow ranges of immediate experience which are wholly similar — operates inevitably to make, not practical thought alone, but all general conceptions also very much the same. In short, as a consequence of the fact that in primitive social life personal experiences of every sort are only slightly diversified, the thought

which is characteristic of all early civilization, and particularly every sort of conjectural thought, tends to become communal rather than individual. This tendency is accentuated by gregarious habit — as we commonly say, through the influence of herd suggestion. It results that in primitive society the only general ideas which become sufficiently well defined to be expressible, are the ideas not of individual thinkers, but of men in the mass: blended mixtures of conceptions similar in kind, which gradually become homogeneous and assume persistent and unvarying forms, the group representations of the anthropologist.

Whenever, as is almost always the case, comparative isolation permits the undisturbed development of any such communal ideas, that is, whenever societies of dissimilar organization and custom do not freely interpenetrate and stimulate by the mutual opposition of their characteristic conceptions an occasional growth of curiosity and doubt and new conjecture, then the spontaneous thought of the individual — which is the source of all innovation in thought and thus of all intellectual progress — is finally completely repressed and the group representations in which it is submerged become remarkably persistent. Since also these representations embody beliefs concerning matters of the gravest social concern, they are always surcharged with strong emotion; the contagion of their influence is spread by ceremony and rite; their authority, enforced by social regulations which express the common will, is established by institutions; they become inviolate and sacred.

All this is familiar enough to every student of sociology. Its bearing upon the present relations of science and religion, however, becomes evident only when we permit ourselves to realize, first, that these group representations have so completely dominated all common thought throughout the period of historical record that many of them — conceived in times so remote that neither the mental process which produced them nor the social conditions which stabilized them can now be clearly understood — still persist among us as unquestioned articles of belief; second, that the conservative tendency of collective thought which has made this possible is still operative; and finally, that the representations which have thus survived are not by any means exclusively religious, nor even religious at all as the enlightened conceive religion, but in their surviving forms consist in greater part of the moral codes of vanished barbaric peoples, and of the primitively imaginative and wholly unverified theories concerning the world of nature which they ignorantly entertained.

Stated thus baldly, this realization is almost as shocking as it is illuminating. It is our inveterate habit to assume that our individual thought, in this enlightened and progressive age at least, is wholly free and spontaneous; and, although we are willing to admit upon reflection that our general ideas concerning the nature of things are derived almost wholly from the knowledge of common report, we nevertheless believe that we could, if we wished to do so and were not too busy, justify them completely by reference to the record of well attested facts. To be

informed that the prevailing thought of our time is still largely dominated and controlled by group prepossessions which are actually prehistoric, fills us with incredulous and resentful amazement. If, however, we allow this amazement to subside, and candidly examine the evidence which everyday experience forces upon our attention, we discover not only that many of these prepossessions are commonly accepted as literally true, but that others, too childlike to be accepted literally, are still so profoundly revered that in order to perpetuate them in the face of contradictory knowledge they are interpreted metaphorically with the cleverest ingenuity; and that others still, transformed by successive reinterpretations, still live as the tacit presuppositions of highly elaborated and subtly intellectualized metaphysical dogmas. The force of the unconscious will to preserve these precious relics of prehistoric science is still so powerful that even among the intellectual they are studied scientifically with reluctance; the conceptions they embody still retain for everyone something of their inviolate and sacred character; there are few men, even now, who dare pursue to its logical conclusion the rational analysis of their development.

Such is the power of group representation in common thought. That the predispositions it engenders long survive the conditions which first ensure its domination of individual opinion is too plainly evident in the characteristically obstinate refusal of the majority of men today to consider fairly any new ideas, or even to accept any new knowledge which tends to undermine their cherished prejudices. We all very quickly

recognize this unreasonableness in our neighbors whenever their ideas concerning important social problems — such as questions regarding government, or property, patriotism, marriage, choice of beverages, or dress — differ somewhat from the wholly justifiable convictions which we ourselves are morally bound uncompromisingly to uphold. It sometimes appears that it is only in the prosecution of their chosen work that they are willingly rational, and then only under an obvious compulsion to be efficient. What wonder, therefore, that all but ourselves and those who agree with us are likewise prejudiced in belief? This conservative habit of thinking is clearly enough the most persistent of all our mental traits. It is, as a matter of fact, the analogue of our equally unchanging physical habit, which is itself the analogue of mechanical inertia — the phenomenon which serves physical science as the basis of all natural law.

To recognize these facts, however, is practically to avert the repressive effect of group representations upon intellectual progress, and at the same time to allay whatever apprehension we still may feel that continued conflict between science and religion is inevitable. When once we become fully aware that our conception of the sacred is, in part at least, a group prepossession wholly human, then the religious mind is free to discard those grosser elements of its belief which contradict our actual knowledge, no longer haunted by the unreasoning fear that the disbelief of venerable absurdities endangers our immortal souls. This catharsis once effected, there remains, obviously, no reasonable ground of conflict

between science and faith; since the domain of science is that of knowledge and of knowledge alone.

Within this domain, however, there is no room for any rival theories of nature which cannot meet the pragmatic test. This test supersedes in practical thought the authority of all tradition whatever and of all emotional evaluation of experience which it suggests: it actually usurps this authority by the assumption of superior right; for ages of hard experience at length have proven beyond all doubt that in this present life — which is the only life we know, whatever be our hope — it is knowledge and not faith which thus far has secured to man whatever progress he has made toward actual salvation. If, therefore, there is to be no further conflict between science and religion, religion must no longer remain in bondage to antediluvian traditions which falsely appear to necessitate her acceptance of unauthenticated legends and primitive animistic beliefs concerning the world of nature. Science will not compromise this issue; for the labors of science, which initially are stimulated by curiosity alone, have come to involve an aspiration as high, a devotion as intense, and a will as determined as those of any faith: a religion of her own, earth-bound, practical, clear-visioned, hard and cold; a religion of Things as They Are, which translates hope into purpose, and prayer into work, for the betterment of humanity here and now.

But, granted all this: what is its bearing upon enlightened religious thought, which already interprets the simple irrelevant beliefs of the multitude precisely as they are here interpreted, evaluates them similarly,

and has no thought of challenging the authority of reason within its own domain? The religious mystic has thought this out long ago, and has gone much further — as far as the scientist himself has gone in the analysis of our keenest thought, and beyond him in all emotional experience. If the scientist labors for the welfare of humanity, so does he; and surely in the end to better effect, since the use to which knowledge is put must be determined by some purpose higher than that of wayward men unguided by ideals, if it is to be a blessing rather than a curse to humanity. And who but he attempts to purify our traditional religion of its dross? To these contentions there is no answer but that of complete assent — so long as the mystic is not himself affected by the group obsessions which keep the religion of simpler men in perpetual bondage to tradition. But his position is as hazardous as theirs; for like the rest he is guided by emotion, and having denied the authority of reason in all but merely temporal concerns, he has deliberately exposed himself to the extreme influence of these very forces. Unable, even in ecstacy, to transcend the ultimate limitations of common thought, it is almost impossible for him not to envisage the world of his desire in the imagery of actual experience. He may dream otherwise but he cannot think otherwise. Even the magnificently imaginative mysticism of the East is unable to escape these limitations.

Nearly always, therefore, revelation, whatever be its actuality, is humanly conceived in earthly images; and though it may be interpreted symbolically, the symbol itself is all that our feeble human thought

can grasp. To the symbols, therefore, we cling; and they become more vivid and definite in religion the longer and more profoundly they are venerated. Our mere will to understand accentuates this tendency toward precise conceptualization; our human love brings it even closer to the world we know, the more certainly because we demand, not vision and understanding only, but comfort and assurance. Thus even the most ineffable of our beliefs tend to become at length intensely and warmly humanized, and thus inevitably they are assimilated to the traditions we cherish. So far from stimulating doubt of these traditions, they give them new meaning and significance; dignifying even their irrelevancies and clothing them completely with new and shining garments of mysterious and supernatural authority. Their very persistence becomes vaguely significant: the veil of antiquity hides their origin; the older and stranger they are, the more we venerate them. 'Men saw more clearly then' we say; and thus it comes about that all that these traditions embody — not only their legends of revelation, but the commonplace experiences and primitive morals and interpretations of nature which are included in the ancient writings which preserve them — are touched anew with the essence of the sacred; become even more certainly inviolable.

The mystic's final truth, once unimaginable, thus ultimately becomes a dogma which, giving new significance to traditions already venerated, blending with instinctive skill the conflicting representations that they embody, and interpreting the whole as an impressive background of new spontaneous aspirations and

beliefs, extends and strengthens the power of ancient conceptions over the thoughts of men beyond its natural influence. The product of superior acumen and subtlety in thought, it dominates the intellect as it thrills the heart of the devout. Organized and propagated by administrative genius, it acquires temporal power, enslaves philosophy and crushes science, and denies the mystic his own prerogative, curbing with cruel finality the madness of his continued dreaming. It becomes an incubus upon the human mind; and even when its institutional power is broken and dispersed, its repressive influence remains unimpaired if not enhanced, for human conscience after the slavery of a thousand years merely deludes itself with the thought of freedom.

This is a familiar story: one which was more intelligently apprehended, to be sure, by our grandfathers than by ourselves, yet even now quite understandable without the aid of chapter and verse citation. It is the story of the old theology — the formal interpreter of mysticism, the activator and protagonist of consolidated group obsession, the tyrant and inquisitor of all modern speculative thought; not philosophy, but the autocratic master of philosophy; not religion, but the stern and unyielding admonitor of religion. This theology is obsolescent now: it has given way to the forces of secularization which, organized and consolidated by the growing power of the industrial and commercial classes during the last three centuries, and animated by their practical intelligence which the rapid extension of scientific knowledge both quickened and fortified, have at last emancipated the

individual mind from directed group control. Its former resistless tyranny, nevertheless, should be remembered, if only as a warning to the easy-going whose excessive generosity of spirit now frequently permits a dangerous tolerance of intolerance itself; and as a warning also to the mystics who unconsciously might again assist — by the influence of the intense emotional stress which their thought engenders in minds too simple to grasp its esoteric meaning — in provoking the reënactment of old tragedies.

These reflections may well conclude this preliminary survey of the scientific habit of thought. Its fragments of commentary and argument when pieced together will comprise an exposition which, if its obvious implications are a little more fully developed, will lack nothing essential to a clear understanding of the general significance of the scientific attitude in thought and life. The characteristic conceptions, methods, and theoretical representations of science may now be discussed in a similarly general way.

II

THE NATURE OF FACT

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To the scientist, as well as to all other tough-minded people, the things that count are facts. What we have called heretofore the pragmatic test is usually referred to in common speech as an appeal to facts. The basis of every scientific judgment, that is to say, is a fact. Obviously, therefore, it is very important to the scientific man to understand with some clearness just what a fact is. To an ordinary person a fact is a fact, and that is all there is to be said about it. If he tries to define it, he describes it in terms which presuppose it, and with growing eloquence he merely enlarges the circle of his reasoning. One suspects, in cases like this, that the question at issue is philosophical, which is another way of saying that it is exceptionally difficult. It would, however, be cowardly on this account to evade it; and would moreover leave us, like the man so sympathetically pictured by Mark Twain — the man whom somebody had called an ass — in doubt. As a matter of fact, the scientific investigator is still struggling with this among other similar recondite problems; and he has already gone far enough with his analysis to make it apparent that a satisfactory definition of fact would involve a very large part of the entire theory of knowledge. A fact is no simple thing. That attention which first introduces discontinuity

into the confusion of our most diffuse awareness, by this act carves out facts. The act in its simplest analyzable form is complicated; it involves discrimination, comparison, trial, judgment, choice. The analysis of fact, therefore, is evidently a matter for research, and means its more and more minute description with reference to action. Facts, then, are the primary data of all thought; those elements of our knowledge which are the necessary terms both of experimentation and of reasoning. The scientist's problem, therefore, is not to derive them from anything else but merely to describe them as minutely as possible, to classify and arrange them — in short, to qualify them in terms of their relations to each other in experience.

Facts are, to begin with, *coercive*. They exist independently of will. This is what has given them their authority in common sense. In the elaborated first philosophy of common sense they exist in the outer world, are not merely subjective; are ubiquitous, not personal. Now in such degree as we can prove this persistent association of independent power and ubiquity in separate or separable existences, while showing that the meanings we assign to these qualifying terms are definite and invariable, then so far as science is concerned facts are unequivocally identifiable; that is, may be defined. The primary necessity of such definition is obvious. Facts are the compelling elements of common-sense experience, a careful adjustment to which is the necessary condition of successful, or even continued living. Ages of experience appear to prove that the failure of common understanding, which means primarily its practical inefficiency, is due

to their imperfect identification. It is an easy inference that scientific understanding must be similarly conditioned, since it is the business of science to describe all experience; not that of thought alone, but that of action also, and for reasons already dwelt upon, that of action first of all. No one doubts that there are coercive factors in general experience which certainly determine action, and also in some degree determine thought and will, though to an extent which is disputable. These existences, science, like common sense, calls facts. They are as nearly ultimate as anything may be assumed to be; for the processes of thought which are described by logic are less universally compelling, and appear from their relation to the rest of experience to be derivative.

It is worth noting that the existences here called facts are what are commonly referred to as physical facts. This qualification is misleading; for it implies that in our world of elaborated common sense they are physical merely, and this is not the case. They belong to the totality of experience, of which the mental and the physical are only particular parts or aspects. It is the first business of science to identify these coercive existences with the highest possible precision; and this act is the scientific definition of fact. We may now briefly describe it, with reference, necessarily, to our inescapable world of common-sense representations.

It will simplify discourse if, first of all, this background is recalled. In the whole of the foregoing discussion, as in all discussion whatever, at all times, the elaborated world of common sense has been tacitly taken for granted, no matter what may have been said

about it. This elaborated world is primarily divided into my personality; a complex of things and events outside it which merge with it through my body; and within this outside world, certain especially interesting existences whose behavior resembles my own, and which therefore I conceive as existences similar in all respects to me: for instance, sensitive, wilful, conscious. Because my own personality is not sharply and clearly separated at any time from the rest of experience, or is, as we customarily say, partly physical and partly mental, and particularly because the degree to which it merges with the rest is quite indefinite, and so variable that there are times when its subjective individuality is completely lost to consciousness, I prefer scientifically not to regard it as a separate existence, but as a fluctuating aspect of the whole complex, which therefore I take as primary and call, without personal qualification, experience. I then regard it, and particularly those vivid and elusive aspects of it which I call consciousness as having been derived from the whole; not, being indeterminate, to have made the whole. I cannot pretend to explain this derivation, but I may hope to work toward a description of it in terms of relations which the whole exhibits. Similarly, consequently, I derive other personalities, identified by analogous behavior in the external part. The scheme of thought thus evolved is perfectly consistent, though in many respects it is necessarily vague; at all events, it does not multiply hypotheses, and it economizes thought as well as nervous energy. It is avowedly pragmatic: an improvement on the commonplace view which postulates three

or more, and then quite dogmatically two independent primary existences neither of which is clearly definable; and, unlike the philosophical simplifications of this scheme which reduce it to idealism or materialism — between which one is free to choose — it involves no unnecessary conceptions. It cannot supplant the common-sense categories in discourse, for reasons explicable in its terms; but it can disentangle many difficult knots in thought. And, incidentally, it does not diminish the high utility of the common-sense categories in any case; for its total world is no more the world of primitive confusion than the naturalist's conception of 'quadruped' is the same thing as the baby's equally general designation of all quadrupeds as 'doggie'. It clarifies without displacing the earlier classification of experience, and one of its clarifications is that of the conception of fact.

Now, if to me personally an experience is coercive it is a fact, but only so far as I alone am concerned. If both you and I have coercive experiences which we agree are closely similar, we identify these experiences and have a fact in common. If all of us so agree, we together identify our like experiences as a universal fact. Our agreement is always some similarity of behavior, say of bodily action or of speech, in the only world we have in common, that is, the objective world. The establishment of a fact in this way is therefore for each of us the observation of consistency among phenomena. In order that this consistency shall be adequate to justify the inference of a universal compulsion, it must be, within a certain range of inevitable approximation in agreement, complete — with-

out exception; and the number of the relations which define it will roughly measure its credibility. For the sake of clearness it is worth while to summarize all this in other words, by saying that a fact is a compulsory experience established by common agreement which is indicated by similar behavior with reference to it; that this agreement will never be absolutely exact, but approximate in varying degree; that within the limits of this approximation, the agreement must be complete, that it must apply to all relations into which the fact enters; and that the number of these relations roughly indicates the probability of its universality.

A few illustrations will clarify, enrich and amplify these statements. First of all, it will be useful to call to mind a few typical phenomena of agreement. For the individual, every experience singled out by attention is a fact: a rock, a river, a star, a dog, mankind, the self; warmth, fever, pain, fear; an earthquake, night; a ghost, a unicorn, a pink frog. Concerning phenomena such as the rock, the river, the star, the dog, mankind and the self, agreement will be easily established by action. Each man will be aware of himself. There will be those who cannot see the rock or hear the river, or converse with men, but they will share partially in these experiences, and be in agreement with other people within the range of their knowledge. Some will have more vivid or more minute or more extensive knowledge of any or all of these things, and if this knowledge is shared by many, even though not by all, it will be accepted by all as a fact if it does not contradict the less inclusive knowledge of any. This procedure permits the extension of

individual knowledge beyond immediate experience by application of the criterion of consistency, and thus admits the knowledge of report, without which our world of individual experience would be meager indeed. It is clear that the consistency required will be more and more securely established, the more experiences of rock and river and so on it involves.

It would be profitless to undertake the analysis of simple identifications of these sorts, which are common-sense experiences. A more minute examination of certain others, however, will be instructive to those who are not intimately familiar with scientific procedures in observation and description. It will be convenient first to consider warmth. A common experience of warmth is very easily established: it is, however, very vague, because the immediate relations into which it enters are not distinct. In such cases, a search for new experiences which may involve the fact is undertaken. Since the experience of warmth is usually simultaneous to many persons, it is conjecturally referred to the outer world; its connection with expanding and contracting air and water and with other phenomena of movement is then observed, and this inference is thus verified; thermometers are invented, and it is henceforth described in terms of perceptible movements as definite as any other common experiences; its complex of relations thus enlarged rid it of its vagueness, and it henceforth exists more richly and vividly as an objective fact than as a sensation. Pressures, lights, sounds and electric sensations are similarly objectified, and made similarly definite, as common experiences easily identifiable by agreement.

It is noticeable that this process always works toward the definition of phenomena by the description of their connection with motion, that is, with spatial and temporal relations. Motion of some sort accompanies all phenomena; and since it is observable with precision, all processes come to be described more and more exclusively with reference to it as observation becomes more minute. Simple persistent existences meanwhile, objects let us say, are for like reasons identified by their form and bulk, or with respect to other characteristic attributes, by aspects of these which may be described in like terms. Thus a crystal of sulphur will be identified by its characteristic shape; by its weight, which may be represented by the elongation of a spring from which it is suspended; by its density, which is the ratio of this weight to its volume; by its refraction of a ray of light, which may be defined with high precision geometrically; by its melting point and specific heat, which involve the determination of temperature ranges represented most simply by the expansion of a gas or liquid — and so on. The momentary conditions of systems of bodies are likewise described, and with reference to these their processes of change in time, by the simultaneous observation of changes in the configuration of systems in regular motion, regularity of motion being defined by the apparent diurnal movement of the stars. Such observations, to be compared, must in every case be accompanied, either simultaneously or in advance, by others precisely similar which are performed under like conditions with standard objects made as nearly as possible invariable, and used either directly, or indirectly

by means of precise duplicates, in all operations of like sort. When this is done a measurement has been made, the result of which is a numerical ratio, one term of which is fixed; so that we may say that at a certain place the weight of an object is so many grams, its volume at such and such temperature and pressure so many liters, its density (thus determined) such and such, its melting point so many degrees Centigrade, and so on. This type of procedure has an incalculable advantage over any other for two reasons. First, it makes every sort of observation as precise as possible by reducing it ultimately to the observation of relative linear dimensions, which are measurable with very high precision. Second, by the use of almost invariable standards, it makes all of them mutually comparable, thus tremendously extending the possible range of factual relationships.

While the identification of facts and factual relationships is thus being successfully developed into a methodically uniform and most efficient routine with respect to rocks and rivers and their like, and to warmth and color and their like, it is inevitable that the practical and economic mind of common sense and of science shall proceed in like manner in the examination of more complicated or more obscure phenomena. Such are natural events like the earthquake, living beings such as the dog, and sensations not easily correlated with objective phenomena as for instance, pain. To consider the earthquake first: This is a sort of experience, which, being more rare than that of rock or river or warmth, is not so easily distinguishable from other similar experiences, and is

consequently not so easily identifiable. Here we encounter the possibility of sharp disagreements which must be reconciled before we can accept the fact. The explosion of a mine actually causes a little earthquake; the experience of vertigo simulates its effects. It is possible to distinguish these phenomena only by the deliberate comparison of more extensive complexes of relations: a process of disentanglement which is frequently difficult and sometimes inconclusive. By determining the extent, intensity, localization and intensive or other qualitative distributions of the effects confused, and by a study of concomitant experiences, this disentanglement may usually be effected, however, if the phenomena have been sharply enough observed.

Earthquakes, tempests and tides, diurnal and seasonal changes of all sorts, — in short, all the processes of nature as distinguishable from its relatively permanent aspects — usually present themselves thus ambiguously; and even the simpler occurrences which common sense easily distinguishes as the elements of such phenomena — the violent or continuous movements of heavy bodies, dilatations and contractions, evaporations, liquefactions and solidifications, noises and harmonious sounds, the chemical transformation of substances, electrical discharges, changes in brightness, color or warmth, and so on — are themselves immediately recognizable as effects only a little less complicated. They are also made more difficult to identify by occurring simultaneously. Moreover, as observation becomes more minute, those which have been looked upon as relatively simple become less and

less easily describable; their formulation grows increasingly complicated; in short, they assume the appearance of those which earlier experience has roughly shown to be compounded effects. These phenomena therefore are themselves assumed provisionally to be likewise compounded, and so on, progressively. The last step in this analysis is carried out, whenever possible, by experiment.

In all scientific investigation, the procedures of experiment, to which accurate measurement is in the end merely contributory, are the most important. In common speech we use the word 'experiment' very loosely indeed, to mean almost any sort of test or trial. Scientifically, on the contrary, it usually has a particular signification, a clear understanding of which is necessary, and indeed is almost sufficient for the intelligent appreciation of scientific evidence: that is to say, for a full comprehension of the meaning of scientific fact. The characteristic rôle of experimentation in methodical procedure needs first of all to be outlined, if this meaning is to be fully grasped.

Natural processes of all sorts, whatever their magnitude and range, present themselves as complicated effects. By the employment of every means at its command, common sense seeks to reduce their confusion to some sort of order by disentangling from one another and rearranging in additive relation the simpler occurrences of which they seem to be compounded. The first act of this analysis appears to

be the observation of similarities or analogies among diverse occurrences; and since the range of common knowledge is wide, and ordinary perception very keen with respect to all events which are of possible significance in the adaptative conduct of life, such observation is usually quick and sure. Since also an aptitude for this sort of practical thinking has been developed by the unremitting effort of ages under the spur of inexorable necessity, it is frequently subconscious, and the judgment based upon it, as we say, instinctive. The consequent analysis, comparison and classification of natural phenomena in the rough by common thought thus penetrates very far — much further than we unreflectingly suppose; and more certainly than we are aware, until by deliberately attempting various regroupings of our customary correlations we find ourselves ultimately forced by the mere weight of cumulative evidence to abandon the subtlest of them, and revert to our common-sense classifications. The permanence of these classifications is thus at once demonstrated and explained. They are the result of countless adjustments and readjustments of ideas to facts, over the total range of the unimaginably diversified common experience of ages.

These processes of ordinary thought, when they are retrospectively rationalized, are what we call the procedures of inductive inference; which, roughly speaking, means the discovery of persistent similar elements in different experiences, and the classification, arrangement and final generalization of these with reference to their common characters. This is fre-

quently referred to briefly as the inference of general truths from particular facts. This definition, however, emphasizes unduly a single aspect of the process: the discovery of inclusive similarities. In scientific as in common thought, the simultaneous identification of characteristic differences among similar phenomena is quite as significant, and is, indeed, that aspect of inductive thought which is the more fertile. The end of inductive reasoning, it is proper to say, is generalization; but generalization is never complete, and its effective elaboration is possible only as a consequence of progressively minute discrimination. In short, the synthetic and the analytical aspects of the process are complementary and inseparable. If it were ever ended, a complete synthesis would embody all of its results; but it is never ended. It must be borne in mind also, that excepting in methodically developed procedure this inductive thought is not the patient unimaginative collection of particular experiences and their subsequent classification by the routine tabulation of common characters. A philosopher in meditative leisure might imagine such a procedure, and a completely baffled scientist might adopt it as a last resort. But usually, in common and scientific thought alike, it is possible to alleviate this tedium by guessing; and almost always this is done. A first inductive inference, frequently so quickly made that it is not recognizable as such, and is conceived as an inspiration or a fool's idea according to circumstances, flashes into thought and claims verification by trial. The imaginative mind is peculiarly fertile in such notions. Very frequently

they have the slenderest original justification in consciousness, and are correspondingly hazardous as guides to judgment and action; but often they may be so easily and so quickly tested, that by indulging their claims, incalculable time and labor may be saved in constructive thought, despite their high mortality in the contest with facts.

This abbreviated inductive procedure is called scientifically the method of hypothesis and verification. Its history is peculiarly interesting and significant. In the childhood of science, among the early Greeks, all natural impulses conspired to accentuate the seeming value of the guess itself. The exuberant enthusiasm which inevitably accompanied a first free exercise of the unfettered imagination was too intoxicating to be effectively dampened by the dull admonitions of prudence. Vivid pictures of the world, poems of nature unverified but beautiful and inspiring, multiplied themselves. But then they came into conflict; and those among the dreamers who were more intellectual than poetic began to examine their consistency in thought. This was the first procedure in scientific verification — the determination of consistency in thought. It established what may be called a metaphysical criterion of judgment; led to the formulation of all our problems of conceptualization, and produced at length a philosophically defensible atomic picture of nature, of which our own marvelous atomistic representation is the factually justified elaboration. Aristotle, however, having demonstrated the insufficiency of this type of representation to explain the processes of life, substituted for it a genetic theory

of the world based on more inclusive and more careful inductive inferences; and meanwhile, the Greek astronomers, guided by the plausible supposition that celestial motions could all be described as compounded circular motions, devoted themselves to an even more careful study of phenomena in attempts so to represent the movements of the sun, moon and planets. Thus the minute observation of facts, and in the single realm where it was then possible their measurement also, established a second and more general standard of verification: a consistence not of ideas with ideas alone, but of ideas with events; a complete consistence, known to the Greeks as the saving of the phenomena.

After this, a relatively short time elapsed before it was fully realized that with respect to terrestrial processes, mere observation was seldom adequate to yield anything more than a rough and superficial analysis. The methodical study of isolated phenomena artificially controlled was then undertaken, successfully, as everybody knows, by Archimedes, and later by Ptolemy and others. This was, if not the first, at least so far as we know the first systematic scientific experimentation. From the earliest times, certainly, the varied techniques of practical engineering and industry had involved such testing of phenomena in detail, but very rarely for theoretical purposes. It was the adoption and philosophical development of these procedures to serve the ends of pure research which marked the beginning of scientific experimentation properly so called. It will be remarked that originally experiment was resorted to only when a satisfac-

tory analysis of phenomena could not be effected by inductive inference from observation alone. It was long before its possibilities came to be realized; and this was not merely a consequence of the religious revolution which destroyed Greek science in the most promising period of its development. To astronomy, the most highly developed of all the natural sciences in this period, experiment obviously promised little; biological and medical knowledge was not then sufficiently profound to take advantage of the opportunities it presented; and after the infertility of the Aristotelian philosophy was apparent, and all theorizing consequently fell into disrepute among scientists now grown overcautious, hypothesis itself was discouraged, and its peculiar method of verification commonly disregarded. The skeptical empiricism which then arose was developed, therefore, imperfectly. Its chosen methods were wholly inductive, and though it thus encouraged minute and methodical observation, and within the scope of its influence was thus scientifically as well as philosophically productive, its effect upon the development of the fundamental physical sciences was repressive. This ancient empirical habit was well represented in modern times by the inductive methodology of Francis Bacon, sound enough in itself, but so clumsy and ineffective that even the patriotic British scientists who proclaimed themselves his followers were such by word rather than by deed. With Descartes, however, the theoretical scientific method of the Greeks was revived; and when, at the same time, the experimental procedures which their later work had foreshadowed were suddenly and

brilliantly developed by Galileo, Gilbert, Boyle and Harvey, the renaissance of science was complete; for the general methods of research which were then blocked out are those which we still follow.

This historical sketch is sufficient to define the rôle of experimentation in the scientific analysis of complicated events. Today we employ all of the ancient methods, for all are useful; and, speaking generally, we apply them in the order of their historical evolution. With the rapid growth of scientific knowledge and aptitude in modern times, these methods have, of course, been elaborated by the incorporation of many new and effective devices both conceptual and practical; and in the investigation of particular phenomena there are innumerable variations of procedure, since the character of any new problem always suggests some advantageous modification of customary practice. In different cases circumstances thus permit the abbreviation or elimination of one procedure, or compel the extended development of another; and specific schemes of verification in detail are consequently nearly as various as the problems to which they are applied. All of them, none the less, may be legitimately looked upon as variants of one general procedure; like the methods by which particular algebraic equations are solved, which, however singular and ingenious they may be, may always be described by reference to a typical general equation.

This general equation of scientific method, so to speak, may be characterized broadly in the following way. The discriminations of common sense, and in the rough, the classifications to which they lead are —

whenever they do not embody the vestiges of errors derived from early ignorance — provisionally accepted, as Aristotle advised, in bulk; and we allow this commonplace analysis of phenomena to carry us as far as it can. It is upon this basis, then — a very solid basis as we have already observed, buttressed by a tremendous mass of thoroughly tested inductive inferences — that the scientific structure is built. Thus the foundation of this structure is a description of all phenomena which are simple enough to permit complete analysis in the ultimate terms of primitive apperception, instinctively apprehended as such by the early Greeks and clung to ever since as the unanalyzable elements of pragmatic thought: the terms of perceptual extension, duration and coercion; formulated as distances in three dimensions, uniformly flowing time, and mass, force or energy — and always as simply as possible for the purpose of economizing thought.

A uniform scheme of conceptual representation having been thus established, phenomena which are to be analyzed are carefully and minutely observed, measured with precision in many ways if possible, and accurately described. Comparisons made in the common-sense manner then usually suggest hypotheses to account for their peculiarities. Our favorite procedure nowadays is to guess both quickly and frequently, depending almost wholly upon our procedures of verification to establish the truth or probability of our successive conjectures, or to invalidate them. This is now a more effective proceeding than that of cautious inductive inference; because as a

consequence of the high development of methods and devices for verification, it is much more rapid. Formerly, for lack of these means, it was better method to proceed more slowly and surely; and even now this course is advisable whenever confirmatory procedure is difficult. If satisfactory verification is impracticable, obviously, the only possible procedure is that of complete induction; but this is never resorted to if it can be avoided. Thus, the method of hypothesis and verification has now become the typical scientific procedure in the analysis and correlation of phenomena; and its critically important phase, which now, one might almost venture to say, alone distinguishes it from the very similar procedures of the imaginative arts, is that of verification.

A scientific hypothesis is always verified in two ways. It is tested first of all for consistency with the rest of our experience in thought, that is, metaphysically, in the ancient manner. As a consequence of the sharp definition and clean-cut correlation of all of our basic scientific conceptions, this procedure, which is logical, may now usually be much abbreviated; and inasmuch as scientific theory grows by successive increments and corrections on the whole rather gradually, it is only in exceptional circumstances, as when inclusive correlations are radically revised, that it need now demand more than momentary attention. Its necessity, however, is obvious; and the consistency of new formulations with those which are generally accepted is always established before they are seriously considered, excepting in the rarest instances, and then only for sufficient reason.

This done, the hypothesis must next be tested for its consistence with the rest of experience, in the world of events. This critical verification, which alone can establish complete consistency or pragmatic truth — the only truth which science recognizes — may sometimes be made directly. More frequently, however, since the hypothesis naturally embodies suggestions which are not directly inferable from facts already known, it must, before this is possible, be deductively transformed; that is, its implications must be worked out logically until some of these present themselves in the guise of statements of observable fact. This deductive elaboration of hypothesis is clearly a very important procedure. In physical science usually, and always whenever the hypothesis may be exactly formulated, it is carried out mathematically. The rôle of mathematics, and more generally that of formal logic, in natural science is thus explicitly defined. The power of these instruments of research is tremendous. By revealing the remotest implications of every conception which they elaborate, and in many other ways which must yet be discussed, they completely ensure the conceptual consistency of the whole scientific synthesis, and in so doing yield theoretical generalizations of the widest scope and most profound significance. When hypotheses are thus, or more loosely in the ordinary logical manner, deductively elaborated, it frequently happens that they yield inferences which are immediately substantiated by known fact or may be confirmed by new observations of uncontrolled phenomena. The theory of universal gravitation, for instance, was thus estab-

lished. In physical science, however, these inferences must usually be tested by observations which can be made only after the effects they prophesy, presumed for the time being to be existent, are separated from the complexes in which they are alleged to occur, and examined either apart or in simple determinable relation.

The procedures of experimentation are designed to this end. They are, clearly enough, the most important of all scientific methods; for although they are guided to inestimably great advantage by the results of logical and mathematical investigation, they may of course be carried out independently on the basis of mere guess-work; and it is not to be forgotten that much important scientific work has been, and is now when mathematics is inapplicable, conducted in this manner. No amount of logical or mathematical investigation alone, moreover, can ever establish a fact. And, finally, since with the growth of our knowledge all scientific theory tends to assume the forms of physico-chemical generalization — astronomical, geological and biological investigation having already become largely physico-chemical — it is apparent that experimentation, which is the final method of verification in physical science, is of all scientific procedures whatever, the most significant. It is for this reason that all natural science is commonly thought of as primarily experimental. This is not, of course, the truth. Vast ranges of experience are still and must always remain inaccessible to experimental method; but the logic of events, which is obvious enough when once its course is traced, compels every scientist finally

to verify his theories by experiment in every possible instance.

The procedure of experiment, usually, is first to make a guess, guided by analagous past experience, as to what phenomena in any complicated effect to be examined may under the conditions be possibly compounded, or, in scientific phraseology, superimposed. This decided, hypothetically, it is then usually attempted to control all but the one which is to be looked for or examined, and then to observe and, if possible, to measure this. The control consists either in rendering the effects to be eliminated constant, or in measuring them simultaneously, or in doing both these things. Procedures, of course, are various and complicated: this is about all which may be said of them quite generally. The results of separate experiments, repeated so as to make possible an estimate of their precision, and performed under changed control of the influences to be eliminated, may then be compared. If they do not agree within the uncertainty of their determination, the method of procedure may be changed in order to reveal superimposed effects which possibly may not have been originally taken into consideration — and so on. Each of the effects which are supposed to be compounded is thus investigated, if the work is complete; the last series of results being a check on the accuracy of the others. There are, of course, short-cuts, variations and amplifications of such procedures. Their final results are those of individual observation. These, then, are confirmed by other observers who repeat the procedures, or more profitably undertake the same investigation by different procedures; or else

the results as they stand, after the experiments by which they were obtained have been publicly described and critically examined by competent men, are accepted on the basis of their consistence with other evidence. If this consistence is lacking, and if no fault can be found with the conduct of the work, there is apt to be some excitement if the results are interesting; and a wealth of new relevant data is then amassed. Every consideration which influences good judgment is brought to bear on the problem of acceptance or rejection; and a new discovery is seldom admitted to be a fact before its consistence with established facts within wide ranges of determined relation is somehow demonstrated.

It is interesting to observe that the procedures of this experimentation are guided throughout by the hypothesis that complicated effects are compounded of processes which occur independently; that is, without affecting each other's character. This assumption is wholly pragmatic. It is justified because it provides a means of describing phenomena in a simple way, and as the concordance of results ultimately demonstrates, consistently. This is the result sought, and the only one possible in experience. Whether phenomena are really of this compound character is a question which transcends scientific knowledge: they are representable and reproducible as if they were so, and this is sufficient, according to pragmatic philosophy. It is not impossible that they might be otherwise representable: this is an entertaining thought, but so far a fruitless one; and this settles the matter for science, so long as the representations which are now accepted

continue to yield an increasing richness of knowledge. We have, therefore, dignified this surpassingly useful assumption as a principle: the principle of independent causes or superimposed effects; either one, since, empirically considered, cause and effect are merely antecedent and consequent, invariably concomitant.

There are many phenomena, like the star, the earthquake, the dog, and fever, in the preceding list of illustrations which (as has been suggested) are either not at all or only partially controllable, and which, therefore, are in varying degree insusceptible to experimental investigation. These are preëminently the astronomical phenomena; but geological and physiological phenomena are likewise obstinate in their resistance to the application of methods such as those described: the first because the tremendous forces of nature are only partially reproducible in the laboratory; the second because the activities of organisms, excepting the very simplest, cannot be reproduced outside the animal or plant nor separately in it without an abnormal disturbance, the effect of which upon the process investigated is usually not precisely definable.

To the extent that experimental methods are thus inapplicable, scientific investigation obviously is forced to the direct examination of phenomena as presented in all their complexity, and its only method of rendering them intelligible is, first by the intercomparison of a multitude of precise observations to discover such similarities as they present; then by the classification

of these, to discern their common characters; and thus, by successive elimination of differences, to arrive, if possible, at a few simple truths which are applicable to wide ranges of phenomena. This having been done, the original complication may be reconstructed by the orderly addition of selected differences originally subtracted — which themselves, meanwhile, may have been similarly classified with reference to other evidence as accidental or significant — and thus made understandable. It is clear that this is the familar inductive method of common thought, the initial procedure in all inference; only slightly disguised, even to unfamiliar eyes, by its extended and frequently technical elaboration and systematic development. Its character in any particular type of investigation is naturally determined by the character of the phenomena, the regularity of which may frequently permit its very considerable abbreviation, particularly by the utilization of general hypotheses partially substantiated: but generally speaking, it is a very slow procedure, and when the phenomena are complicated, an uncertain one. This is because classifications, obviously, may be effected in various ways, and choice between them usually involves the multiplication of merely probable judgments. Moreover, in the absence of that opportunity for frequently repeated verification of intermediate inferences which experiment provides, it is impossible to test the validity of a chosen grouping in any particular aspect until as a whole it is extensively worked out. The experimentalist is permitted to test his inferences as he proceeds; the scientist who is compelled to extend the inductive

method over the whole range of his work must elaborate at least in the rough an entire conceptual scheme which derives plausibility only from a large mass of laboriously acquired evidence, before he may verify it; and he misses meanwhile that remarkable stimulation of the constructive imagination which the frequently repeated examination of residual irregularities provides.

The comparative study of scientific methods which yields these generalities, and which alone can fully justify them, is properly the business of the history of science; and cannot profitably be briefly summarized, since types of procedure, both inductive and experimental, are various and merge into one another. It will, however, be instructive to compare in gross outline two sharply contrasting illustrations of non-experimental procedure.

Early scientific astronomy, after numerous guesses concerning the possible physical constitution of the heavens had been rejected as unverifiable, confined itself to the study of celestial movements. The inductive procedure in this case was made exceedingly brief by the quick perception that apparent stellar movements are all alike, and that those of the sun and moon resemble them very closely; all being circular, and, in comparison with every other type of recurrent process known, fatefully regular. In the absence of any knowledge by which the planets could be distinguished from the stars otherwise than by their apparent size, brilliancy and irregularity of movement, and in the absence of the slightest possibility of correlating size and brilliancy with irregular motion, it was almost

inevitable that the inference was made that all celestial movement was that of compounded circular motions, and directly from the phenomena that the center of every system of such motions was the earth. Hence, ultimately, arose the Ptolemaic theory. Meanwhile, when the relativity of motion had become thoroughly appreciated, Aristarchus suggested a similar but heliocentric theory, which, however, was rejected as a gratuitous complication. Henceforth, nevertheless, there were two possible conceptual schemes by means of which the apparent celestial motions might be equally well described. The Ptolemaic theory prevailed only because it was in direct accord with sense impression and because its premises were simpler: more easily understandable. It was worked out so successfully that these premises seemed well substantiated; and although the later Greeks were as familiar with conic sections as they were with circles, no attempt, so far as we know, was made to change them. When Copernicus revived and perfected the Aristarchan scheme, he still worked with uniform circular motions only; and the advocates of his new astronomy could offer no arguments in its support which were wholly conclusive. The two theories existed side by side for a century, and it appeared to many that there was little to choose between them in principle: the Copernican was less complicated, more closely in accord with the phenomena, but still affected by discrepancies which were much greater than errors of observation.

It is to be noted here first that the premise of compounded circular motions which characterized both

theories was an inductive inference, though one very quickly arrived at — that is, as we say, a guess or hypothesis — which had been developed in two ways, between which after centuries of investigation no final choice could be made. This choice, in fact, was never made, although the heliocentric hypothesis itself survived. The two systems were both discarded when Kepler, having failed repeatedly to devise any system based upon their common mathematical premise which would accord with Tycho's accurate data, at length announced his beautifully simple and completely satisfactory theory, in which the planets were represented as moving in elliptical orbits. This theory itself, however, was then substantiated only by its very much closer accord with the planetary motions as observed; and past experience might well have suggested that its ultimate fate was equally problematical. It had, however, accomplished something more significant.

In both the Ptolemaic and Copernican systems all centers of revolution were, necessarily, points in empty space: the Keplerian system, on the contrary, placed a celestial body, the sun, now believed with reason to be material like the earth and moon, at the common focus of all the planetary orbits. The experimental science of dynamics was meanwhile being developed by Galileo, and within half a century later had reached the stage of exact conceptual formulation. When, as inevitably, its results were applied to the interpretation of astronomical motion, they were, thanks to Kepler's labors as well as to those of Newton and his successors, found applicable; and then, for the first time, despite centuries of inspired work in astronomy,

an unequivocal fact concerning celestial movement was established: that of universal gravitation. It is possible to conceive that terrestrial dynamics might have been developed without recourse to experimentation up to a certain point; that the final tremendous coördination might have been achieved in the rough on the basis of hazardous hypotheses derived from direct studies of complicated phenomena, as Kepler's laws had been derived. There is no doubt, however, that it would have been a heart-breaking labor, which excepting for happy accident would have been extremely protracted; and it is certain that in the end it never would have been verified with conclusiveness excepting by a multiplicity of concordances between theoretical inferences and particular facts which measurement with instruments experimentally designed alone could demonstrate. Excepting for experiment also, astronomy must have remained forever a purely mechanical science of restricted range: it is spectroscopy and like procedures which have yielded us our only knowledge of actual movements in stellar space, of the greater celestial distances, and of the dimensions, constitutions and internal energies of the stars.

The task of the biologist has been essentially far more difficult than that of the astronomer, on account of the extraordinary richness and complication of the phenomena with which he has had to deal. Among these there is exhibited no striking uniformity of behavior to compel attention and to suggest immediate inference. On the contrary, hypothesis appears at the outset to be, if not impossible, at any rate, futile. It was the vivid appreciation of this high probability

which led Hippocrates to the first systematic development of scientific inductive method, which stimulated Aristotle's stupendous and epoch-making analysis of the actual processes of thought, and which later, in the methodical procedures of Alexandrian physicians, raised philosophical skepticism from a mere gospel of doubt to a permanently valid though partial formulation of the principles of scientific judgment. Methodical experimentation, to be sure, was not wholly neglected in medical and biological work even among these men. The eclectic Galen, in whose practice all of the effective methods of his predecessors appear to have been summarized and systematically developed, undoubtedly experimented methodically on living animals. Also, in modern times, experimental methods analagous to those by which Harvey had demonstrated the circulation of the blood were frequently employed in physiological investigations even before the discoveries of Lavoisier opened the path which finally led to the systematic application of physico-chemical experimental procedures in this field of research. For centuries, nevertheless, biology in all its branches remained characteristically an inductive science, which was of necessity developed very slowly by the accumulation of vast masses of data so intricately interrelated that even after the development of miscroscopic method it long remained essentially a science of classification. The labor involved in the correlation of this knowledge was stupendous, but its ultimate general result was not less so; for this was the comprehensive fact of organic evolution, a purely inductive generalization. During all this time medicine, to be sure, was

in a crude way experimental; but its positive achievements, before Pasteur and other chemists made its modern scientific development possible, were very few; and its ridiculous and tragic errors, results for the most part of confused thinking, reckless enthusiasm and ignorant pretension, are the best evidence we possess of the almost insuperable difficulties which even the simplest biological phenomena long presented to the impatient thought of men. Even now, biology in all its branches is still in greatest part inductive, as the inclusive definition of any animal species, such as dog, or physiological condition, such as fever, would sufficiently demonstrate.

These instances recall the last of our original citations of typical individual facts. Of these the first was fear. Concerning this emotion, or any other, it is very difficult to express one's self with clearness. The symptoms may be described, as those of disease may be described by the patient, but usually with even greater vagueness. Nevertheless it may be thus identified sufficiently well to be recognized by all humanity as a compelling subjective experience which is associated with characteristic action, and which therefore is a fact. This recognition itself, however, is more immediate and certain when the behavior which accompanies the emotion is closely observed; and it appears to be the case that no precise definition of the whole condition is possible excepting by the study of its objective aspect. Moreover, such study alone permits the em-

ployment of our most valuable method: that of experimentation. The case is closely analagous to that of warmth, which has already been discussed. Warmth may be described after a fashion, but it is much more profitably measured; similarly fear or any other emotional condition, it is now believed, may be more profitably measured; or if this is not yet possible, diagnosed, so to speak, as physiological conditions are diagnosed by the biologist and the physician through inductive inferences from bodily condition and behavior, checked whenever possible by experiment.

Psychology, which is the science of phenomena of this sort, is thus becoming, in common phrase, more and more behavioristic. The preceding remarks are sufficient to make it plain that this treatment of these most obscure of all phenomena is thoroughly consistent with the rest of scientific procedure, and like all other choice of method is guided solely by the dictates of necessity or advantage. There exists no malicious desire on the part of scientific men by this seeming materialization of the passions of the soul to shock the sensibilities of the poetically minded, though the invitation to do so is almost perpetually forced upon them in a manner which inevitably excites whatever small-boy instinct for mischief may survive among them. The scientist's business is to learn as much as he can. Ever since the time of Socrates, men have studied the workings of the human mind from the inside; and since Locke, intensively. Excepting for the development of formal logic by this method, its scientific results, though by no means meager, have been far from conclusive. Psychologists, therefore, following the

example of all other scientific men, are now trying out the possibilities of a study of the physical aspects of these phenomena. Their purpose is wholly pragmatic: it involves no metaphysic whatever, and is therefore no more materialistic than any other phase of scientific analysis. Neither is it, by the same token, idealistic: it is without prejudice.

If the scientific attitude in this instance be fully appreciated, a great many bogies which still haunt ingenuous popular thought concerning science as a whole may be shooed forth into the limbo where other similar bugbears now lie forgotten. As a consequence of our incorrigible habit of interpreting every representation in thought as a theory of final truth, the majority of us still regard the mechanical scheme of nature, which science so graphically and impressively depicts, as a materialistic philosophy. Enough has been said already to make it evident to any candid person that from a strictly scientific point of view this interpretation is quite false. The scientist establishes his pragmatic truth by referring to the world of events — loosely termed in common speech the material world — because he must do so if his correlations are to be general; and with reference to this world he expresses his thought in mechanical terms whenever possible, because of all forms of representation these alone are sufficiently clear and exact to permit the development of fertile methods of inquiry. This mechanical scheme is insufficient to explain the totality of phenomena, as Aristotle long ago pointed out, and as those who call themselves vitalists still almost unnecessarily insist; but there exists no other form of representation which

permits a comparable precision and fertility of thought. The scientific tendency to materialize all representations of nature, therefore, and further to describe all phenomena so far as this is possible in mechanical terms, even the present tendency to ignore the commonly assumed existence of an independent world of mind — all this is simply the result of a single-minded effort to make our rapidly expanding world of experience not philosophically significant in any particular way, but merely intelligible. Science is contented to present this useful synthesis. The problem of its interpretation, which from the scientific point of view is one which we are not yet prepared to solve, if indeed we shall ever be in the position to do so unequivocally, is one which scientists have trained themselves for efficiency's sake to neglect. Scientific materialism, in short, is method; philosophical materialism is another thing altogether.

It would not be wholly fair to assume that the usual failure of common thought and the not infrequent failure of philosophical thought to make this rather important distinction is completely without justification. Scientific men are not at all times scientists. Outside the laboratory and the study they are not dissimilar to other human beings: they are susceptible to excitements and thrills, and are apt to discuss extraneous matters — politics, or love, or the absolute — with more candor and vivacity than caution; and not all scientists, by any means, have completed their pragmatic training. It therefore frequently happens that the fringes of scientific thought, with which alone the majority of cultivated people are familiar, are

colored by confused spectra of vague opinions and beliefs which are not, properly speaking, scientific at all. Among such beliefs, naturally enough, a simple faith in the ultimate reality of the material world, the faith which philosophers call naïve realism, is often dominant; and since this belief is apt to be rather harshly enunciated by unpoetical men who by habit express themselves as curtly as their polysyllabic technical language permits, it is occasionally very forbidding indeed. Thus the vital germ of science, which is genial, tolerant, and inconclusive skepticism, is concealed from the common view by an external husk of prickly dogma which discourages popular curiosity. Few cultivated people, therefore, are familiar with genuine scientific thought. In conversation they almost never encounter it, and even in the critical and historical commentaries which they occasionally read they seldom more than glimpse it, for, speaking generally, these works have been written by humanists and philosophers of one sort or another whose experience in this particular has been similarly limited, and the intensity of whose interest in the history of ideas has usually, in our Christian era, been proportional to the influence of these ideas, not upon the growth of knowledge but rather upon the development of ultimate beliefs either theological or metaphysical. The typical thought of the scientist finds its normal expression neither in conversation, nor in popular lecture, nor in critical commentary, but in scientific procedure. It is the thought which is the instrument of action: a philosophical variety of common sense, rarely meditative, always purposive and practical; and it is to be dis-

covered in a state of nature, so to speak, vital and productive, and unspoiled by self-consciousness, only in the laboratory itself, or reflected in the homely pages of the professional record. It is, to return momentarily to our original subject of discourse, a type of thought which can be properly psychologized only in behavioristic terms.

Finally now, in this survey of the varieties of factual experience, our interest and attention is compelled by certain other phenomena, for ages very puzzling indeed, and in the history of human thought and behavior very consequential. These are the hordes of strange creatures which it has been convenient to represent in the foregoing catalogue by ghosts, unicorns, and pink frogs. Today in common thought such experiences are dismissed from serious consideration as mere figments of the imagination: we call them illusions. Formerly, however, and not so very long ago, they were held in no such low esteem. They were facts, and very potent facts. Ghosts were plentiful, not only in dreams, but in waking experience; and their still more horrid familiars, werewolves, vampires, witches and devils, haunted not only the eerie solitudes of silent glen and thundering crag, but even the sunlit shores of the sparkling sea, where irresistible sirens lured lonesome sailors to their destruction. They were very real indeed: as real as the gnomes and fairies who sported in pleasant woods and fields; as real as the white angels of the air. No fig-

ments of the imagination, these. They played their part in the great world — a terrible part, as the history of demoniacal possession alone is sufficient to prove. Their record is almost as black as that of man himself. They belonged not to his world of thought alone, but to his cruel world of action; and only recently have they been driven out of it.

These beings were, of course, the remnants of an incompletely differentiated primitive experience: vestigial evidences of the extraordinary difficulty with which our common-sense division of it was made distinct. They and their kind, like all other ideas, still possess this factual aspect, since they continue to affect, though slightly now, our fairer external world. While all humanity were agreed that they were objective existences, and acted upon this belief, they certainly were universal facts by all possible tests. It was only after ages of experience had shown their impotence to bring about changes in the world of events excepting through the interposition of man, their invariable and exclusive association with human activities, and their concomitance with strong emotion, particularly fear, that they were at length proved to be subjective, that is, illusory. It was neither logical argument nor revelation which banished them from the objective world, but knowledge alone: slowly accumulating evidence which finally became overwhelming. Their less noxious congeners, of whom the unicorn is an example — centaurs, chimeras, salamanders, basilisks and the like — had long before been easily disposed of; since, even when they did not confess themselves the children of ingenious fancy,

they were, unlike the ghosts and devils, known only through report. The pink frog, along with other sticky and loathesome products of the witches' cauldron, was likewise, though he was more intimately known, easily identified by his invariable association with delirium or indigestion. These so-called fictions, then, were facts, and are facts still; but now they are psychological facts associated with disease, distemper and intense emotional disturbance, principally that of fear; and are dealt with professionally only by the anthropologist, the psychologist, — and by the humorist, who himself provides psychology with much similarly interesting material.

Let this complete our survey of the principal types of fact, and of the methods and devices by which they are determined: a survey which has led unexpectedly far into the body of professional scientific lore. The important task remains of examining somewhat more minutely the nature of fact in general; of identifying, if possible, the qualities which are common to facts of every sort, in order that the essential character of scientific knowledge, considered as a whole, may be correctly apprehended. The complete inductive procedure by which this character is revealed could not, obviously, be fully illustrated, nor even comprehensively described in a manner sufficiently clear to be convincing, excepting by wearisome descriptions and comparisons of a large number of typical instances. It is, however, possible, by the examination of a single

bundle of closely related facts, to draw particular inferences which, in accord with a consensus of competent opinion, may be accepted as generally representative. Almost any such collection would serve, but discussion will be abbreviated if one is chosen which will represent our most exact and best attested knowledge; for since, as we are already well aware, no factual knowledge is absolute, our interest will naturally be focussed upon the character of its limitations, and this being so, it is legitimate to assume that the defects of our most dependable general knowledge of fact will be characteristic of all such knowledge whatever. The science of chemistry provides us with the richest variety of such collections of facts, among which for the purpose in view there is little to choose. An attractive subject is silver.

In any chemical compendium one may find statements like the following concerning silver: that it is a chemical element of equivalent weight 107.88; a metal which melts sharply at about 961 degrees on the Centigrade scale, crystallizes in cubes, dissolves in nitric acid but not in hydrochloric acid, and forms with these two substances respectively colorless and transparent rhombic crystals which blacken organic matter, and a white opaque solid which turns violet in sunlight. These citations are quite sufficient to illustrate rather fully the more important characteristics of specific scientific facts. They may to advantage be separately considered, in a slightly different order.

The statement that silver is a metal refers to a classification of substances which is practical rather than theoretical, and is useful for purposes of rough identi-

fication: it implies that silver in its usual condition is of a peculiar lustre not simply definable otherwise, and is crystalline, malleable, ductile, and a good conductor of heat and of electricity.

The first statements concerning chemical change — to the effect that the metal dissolves in one acid and not in another, and forms compounds of characteristic properties — refer to facts particularly useful for purposes of identification. Descriptive statements of this sort summarize the bulk of our specific scientific knowledge; they are highly discriminative, and taken together are very precise indeed, since, although they involve no exact measurement, the evidence they provide is cumulative. The methodical comparison of such qualitative facts, together with the convenient routine procedures which they suggest, by means of which different substances may be separated from one another, is the basis, and indeed the greater part of the science of qualitative chemical analysis. Data wholly analogous provide us with the fundamental classifications of other sciences, for instance, those of biology. The knowledge thus elaborated is primarily untheoretical, quite independent of any hypothetical interpretation. It constitutes our great accumulated treasure of specific scientific facts, only a relatively small part of which is as yet theoretically interpreted; and its generalizations are wholly inductive. With reference to the facts here cited concerning silver, which are typical — they are all definable with any desired exactitude, because they are qualitative and involve only simple immediate experiences. It should also be noted, however, that they may be elaborated

quantitatively in various ways, as subsequent statements suggest. With many such data this is not possible; it is, however, commonly the case in chemistry. These facts are also universal, since every specimen of metallic silver among the hundreds of thousands thus tested, whatever its source and previous history, has, we are agreed, behaved in this manner: it is impossible to be certain that all existing silver would thus behave; but this appears to be more and more probable as these particular experiences are multiplied. They are also, with one exception, complete: in no need of qualification. The exception here noted is the statement concerning the insolubility of silver in hydrochloric acid. This was once accepted as a fact, but is no longer so accepted, for minute examination of the phenomenon shows that silver does dissolve very slightly in this acid. The former belief has not thus been proven wrong, for it never meant more than that within a given range of experience silver is insoluble in hydrochloric acid, and this is still a fact and a useful one; with the growth of experience, however, it is no longer a complete fact. The reason that it appears to have been not merely incomplete but false is that, according to our careless habit, we have usually interpreted such statements quite wrongly as pretensions to final truth, rather than as enunciations of provisional truth.

The statement that crystals of silver nitrate are rhombic implies in the first place that although these crystals exhibit a seeming variety of forms, they are all built upon the same geometrical pattern; so that though they may grow more rapidly in one direction

than another, and thus in a lop-sided manner so to speak, the three directions of their growth are always inclined to one another at the same angles, no one of which in this case is a right angle. The further implications of this statement, which summarizes a considerable number of other interesting facts besides, all familiar to the crystallographer, are not immediately relevant. It is sufficient for present purposes to note that the rhombic form of silver nitrate is a fact both universal and without exception, if we ignore the unstable forms of the substance; and that it is also definite in a peculiar sense, inasmuch as the crystal angles may be measured geometrically. When this is done, a physical property of silver nitrate is specified which makes the complete description of the crystal as valuable as any other datum for identifying the substance. The mere statement that the crystal is rhombic has not this value, for a very large number of crystals are rhombic.

The cubic form of crystals of metallic silver is a definite fact also, of similar significance and value; but it is not a complete fact, because silver crystallizes in other stable shapes as well: since, however, these are geometrically related, we may still speak universally of the crystal form of silver by referring to the geometric structure which is common to all these related shapes, that is, by saying that it is isometric.

The statement that silver melts sharply at a particular temperature is, like any of the similarly simple statements concerning chemical change, that of a perfectly definite, unqualified and universal fact of a

type the scientific value of which is very great. It is, in the first place, one of the tests for chemical purity: for all simple homogeneous substances, when their behavior is unaffected by varying pressure, change their states of aggregation at fixed and invariable temperatures, and by the absorption or evolution of heat maintain such temperatures measurably constant in systems well controlled; while mixtures, with a few easily recognizable exceptions, behave quite otherwise. The constant transition points of pure substances are furthermore of great general scientific value; for they provide us with invariable and closely reproducible temperatures which serve as the fixed points of thermometry — a fundamental type of measurement which is essential in nearly all precise physical experimentation.

The designation of the melting point in degrees on a scale thus determined is the statement of another universal fact of a type quite as useful, although it is less definitive because it is quantitative and consequently more inclusive. This sort of fact is best illustrated among these citations by the statement that the equivalent weight of silver is 107.88. The term 'equivalent weight' means the weight, expressed in terms of any unit (strictly speaking, the weight at one locality, or better still, the mass), which will combine with eight identical units of weight of oxygen; and the statement implies that it is invariable. This is a universal fact, since, so far as known, all silver, whatever its origin or history, has, we are agreed, this invariable equivalent weight. This is not to say that we can be sure that such will always be the case. For-

merly all known lead had the equivalent weight of 103.6; now it is certain that samples of lead from different sources may have different equivalent weights, although in all other respects they are precisely alike. This interesting fact and others wholly similar suggest by analogy that silver also may have two or more equivalent weights of which the weight 107.88 is an invariable average, characteristic of the silver thus far examined. Furthermore, the equivalent weight of silver was not always 107.88; for many years (expressed in the same units) it was 108.1; then it became 107.93, and stepwise it has approached the present value. Within the ranges of experience from which these several data were derived, they were formerly universal facts; and since they were originally presented not as final but as approximate data, then despite the greater precision of more recent measurement, they would still have this character excepting for the circumstance that, as is now known, they were determined by the analysis of impure material. It so happens that this source of uncertainty affects the equivalent weight of silver comparatively slightly; but the illustration still holds good: the earlier equivalent weights are no longer considered approximate facts, excepting by accident; for they refer not to silver, but to undetermined mixtures, and are, therefore, as originally stated, false. Finally, the value now accepted as the equivalent weight of silver, even if it represents an invariable property — which is not yet quite certain — and even if it is but negligibly affected by undetected contaminations of the substances worked upon — which is now highly probable

but again not quite certain — is still not an absolute but only an approximate figure. This, like other important physical constants, has been repeatedly determined, and recently with great care and skill by several different men. In order to prove its natural invariability, they have used materials from different sources, have prepared it for examination by different chemical procedures, have made their final measurements by comparing the weight-ratios obtained by the interconversion of different compounds, conducted with extreme care to prevent loss and contamination by different techniques. The final values thus obtained, naturally, have very rarely been identical within the unavoidable error of final weighing. The accepted value is thus an average of results — a weighted average: that is to say, one which is determined not blindly by simple arithmetic, but by the judicious selection and comparison of those determinations alone which are not demonstrably affected by error, and by the relative evaluation of these according to their probable accuracy, by which is meant the result of the shrewdest conjectures which can be made from all available evidence which bears upon the likelihood of their dependability. It has been thus determined, not certainly, but with high probability, that granting the natural invariability of the constant — a supposition which is itself supported by the cumulative evidence — it is known precisely to about five parts in one hundred thousand. The complete scientific result, therefore, is not expressed by the naked figure 107.88, but by the figure 107.875 $\pm$ .005; and considering the fallibility of human judgment, which

in this case cannot be checked by any formal theory of probability, it would very likely be safer to adopt the value $107.88 \pm .01$.

Similar considerations affect the results of all measurements. Thus the melting point of silver is probably $960.5 \pm .5$ degrees Centigrade; the crystal angles of silver nitrate are known with a precision of about $\pm$ 3 minutes of arc, and so on. The uncertainties of such quantitative data are of various sorts, and accordingly they may be relatively small, as here, or very great; and may be estimated with various degrees of probability. The illustration here given is as nearly typical as any. It involves first, an uncertainty as to whether the value sought is really a constant of nature; second, an uncertainty as to whether the conditions of measurement permit a simplification of the phenomena sufficient to make the results of measurement unequivocal. In the present instance, this second uncertainty is largely a consequence of the difficulties encountered in preparing a homogeneous substance to work with. This type of uncertainty affects all measurements of material property: it is evidently, however, only one of many similar sources of error which may be grouped together as instances of uncertainty due to the incomplete isolation of the phenomenon examined; or, stated otherwise, uncertainty due to the incomplete elimination of superimposed effects, which might in different cases be mechanical, thermal, electrical or other.

This determination, like all others, also involves uncertainties of method which are in varying degree influenced by the conditions of measurement. Broadly

speaking, these are of two sorts, represented first by constant errors which result from characteristic defects of chosen techniques or from habitual errors of observation, and second by accidental errors which affect with variability determinations carried out by the same observers in similar manner. The constant errors are customarily reduced by employing different methods, by estimating habitual errors of observation and correcting for them by 'personal equations,' and so on; the accidental errors are reduced by repeating measurements similarly made and averaging their results. It is clear that in estimating these errors, those which are accidental offer the least difficulty. Assuming that no particular cause of uncertainty is operable, it may be expected that by repetition of measurements they will tend to cancel each other, since according to the assumption it is as likely that they will be errors of excess as errors of defect. This being the case, the measurement will become more and more exact as an increasing number of similar observations is averaged. In such cases the mathematical theory of probability is applicable, and permits a determination of final error which, if the number of observations be sufficiently large, is closer and more highly probable than any otherwise estimated. Nice logical problems present themselves in the employment of this device, however, particularly when it is impatiently attempted to apply it to a small number of repeated observations, or to adapt it to cases where characteristic errors of method are to be suspected. If such occur, then, generally speaking, the premises of the theory are no longer valid. The

estimation of constant errors, therefore, is a difficult matter which involves necessarily the exercise of what has already been characterized as shrewd conjecture, and is therefore always highly hypothetical.

With respect to all facts thus quantitatively determined it is interesting and important to note that they are less definitive than qualitative facts only because they involve a much more inclusive complex of experimental relations; imply, therefore, a much more extensive and precise knowledge; and are consequently not only more significant and valuable but, if they are expressed as definable approximations, more useful in stimulating further research. The quantitative determination of facts is, therefore, the most important of all scientific practises; and it is for this reason that despite the highly intricate and minutely technical character of its detailed procedures, they demand more than a casual attention, even from the student whose interest is wholly general and philosophical.

The implications of these simpler statements of fact need not be further developed. It will be obvious to anyone who attempts a similar analysis, even of the simplest facts, that every one of them is an expression of common agreement respecting the relations of compelling experiences; that these relations are of various types and combinations of types, are of widely different range, inclusiveness and complexity, and are valuable for different reasons; and finally that they are in process of change, and become with the growth of knowledge more or less extensive, inclusive, definite and probable, so that they may also become

false. It is thus possible that falsities may likewise become facts: the history of the transmutation of the chemical elements presents a case of this sort. In short, these fundamental elements of scientific knowledge assimilate and grow, coalesce and separate and recombine, shrink and wane, die and come to life again; and while they persist they are never more than probable. Πάντα ῥεῖ: everything is in a state of flux; in a sense, however, that Heraclitus could hardly have imagined.

This mutability of our most dependable knowledge, which the mere description of simple facts thus makes clearly apparent, is seldom remarked in common thought and frequently escapes attention altogether. Ordinarily, because we act habitually in accordance with our best attested knowledge as if this were quite final and certain — and to act otherwise would be to act indecisively and therefore ineffectively — we come instinctively to think of facts as ultimate elements in experience which always were and always will be what they are. This practical habit is so ingrained that the changes which facts all undergo, even when they are conclusively demonstrated, seem half unreal; and as a consequence we often seriously entertain amusingly inconsistent opinions which not infrequently invalidate even our considered judgments. For instance, in this frame of mind, admitting the errors of former belief, we often ingenuously assume that while our predecessors merely held opinions, we ourselves are

in possession of real knowledge which is somehow different. To state this assumption is to exhibit its absurdity; for it will not be very long before in our turn we shall have become the ancients; and our precious knowledge, very likely, in its turn, merely another set of opinions, partly, perhaps, invalidated. It is not impossible that our opinions are a closer approach than theirs to the expression of some final truth; but there is small reason to believe that they have, on this account, acquired any novel and peculiar virtue.

We are accustomed to admit all this with respect to what we call theory; but we balk at a similar admission with respect to what we call fact, forgetting that all that distinguishes fact from theory is the more completely demonstrated consistency of factual relations; that the only experiences which we might without great hazard consider unchangeable are the elements of our immediate awareness, whatever these may be; that all else is correlation and interpretation; and that, in the light of new experience, to reinterpret a fact is essentially to change it. Since the criterion of consistency which establishes a fact must be continually reapplied to an ever-increasing range of experience, it may at any time demand even the complete revision of correlations which have become so habitual that they seem completely fixed; and this makes even facts very changeable indeed. The manner in which they change disguises the process to some degree, and it is probably this which deceives us. Our simpler experiences repeat themselves interminably, and with the progress of knowledge are incorporated as fixed details in our changing picture of the world; but in the process, even

these may acquire entirely new significances: that is, although as details of experience they do not change, as elements of knowledge they may change so radically that their former character is often completely lost.

A few simple illustrations will make the realization of this peculiar type of change — the change brought about by the amplification and consequent reinterpretation of our immediate and elementary knowledge — more vivid. To prehellenic peoples and to the Greeks before Pythagoras, the earth was flat; and as a consequence both of the limited experience of common people and of the perpetuation of ancient Jewish science by the Christian church, it remained so to the majority of men throughout the middle ages. Within the usual range of personal experience today this flatness of the earth is still a thing observed, although, accepting the knowledge of mariners and others whose experience is more inclusive than our own, we now commonly believe that the earth is round — even when, as is often the case, we do not clearly understand why they entertain this opinion. Moreover, to everybody, within limited geographical areas, the earth is flat by actual test. Thus to the builder at work the ancient belief remains a practical fact; and so far as he knows, even if the earth is not a cylinder, as some of the first philosophers of nature believed, it might yet be a polyhedron, on any face of which all plumb-lines would be parallel. Within areas sufficiently small the scientist himself is unable to demonstrate any curvature of the surface of still water, or on level ground any convergence of lines of gravity. The scientist's knowledge, however, embraces all common knowl-

edge of this matter, and much else besides; so that he is able to demonstrate the high probability of a continuous curvature of his hydrosphere, and by the results of measurement show why this curvature is sometimes imperceptible. He thus reconciles an apparent contradiction of experiences; but to do this convincingly, he is obliged to gather together and to extend masses of evidence which only physicists thoroughly understand. Meanwhile, within limited ranges of experience, and for many practical purposes, it is still conveniently permissible to assume that the earth is flat, just as for many purposes it is permissible to assume that silver is insoluble in hydrochloric acid, although this is not strictly true.

Again, to any observer on the earth the sun appears to go round the earth; and it is generally assumed also that this motion is one of simple revolution in a plane, although as an inference from phenomena directly perceived, even this belief could not be justified by the majority, who are unfamiliar with the evidence which proves that the sun does not during the night move around from west to east horizontally as the prehellenic peoples thought. Nevertheless, taking this evidence for granted, everybody knows, or thinks he knows, that the sun appears to go around the earth in a plane orbit: he actually sees it move in this manner through half its course at any rate. Despite the evidence of our senses, however, we all now say that the sun only appears to move in this way; that really the earth goes round the sun. What we mean by this is that, although we actually see the sun go part way round us on the earth, we believe on scientific assur-

ance that to a hypothetical conscious being on the sun, or outside the planetary system, the earth goes round the sun. Very few people, even if they can justify their opinion that the apparent orbit of the sun is plane, are able to justify this further belief, which actually transcends ordinary experience altogether. Nobody, probably, believed any such thing four centuries ago. A very considerable knowledge of astronomy and mechanics is necessary to prove it to be a fact; and it is worth remarking that unless the scientist could explain in terms of his theory thus substantiated why to earth-dwellers the sun still appears to go round the earth, his statements would never be accepted as true.

These homely instances show clearly enough that with the growth of knowledge even familiar facts by successive reinterpretations may change their character completely. In the cases adduced, the original facts remain valid if properly qualified: in other cases they may be falsified; or even, having once been falsified, reverified after false implications have been corrected. The history of the transmutation of the chemical elements already referred to illustrates this sort of mutation. The Alexandrian and the medieval alchemists, primarily as a consequence of their inability to distinguish between pure metals and alloys, believed, or under the influence of seductive hopes imagined, that they had actually converted mercury and other metals into gold. Their earlier assertions to this effect were supported by what was then good evidence; and even later, when more inclusive knowledge suggested that they had been deluded, this could

not be proved, for belief in the possibility of such transmutation was by no means absurd. As late as the middle of the seventeenth century the skeptical and judicious Boyle was in doubt, and rightly in doubt, concerning it. Thanks to his own labors and those of his successors, however, evidence was collected within the following century which proved, so far as wholly negative evidence may be said to prove, that transmutation was highly improbable; and two centuries more of vastly multiplied experiences conclusively confirmed this opinion. It was then accepted as a fact that the chemical elements, which were now satisfactorily identified as substances chemically undecomposable, could not be converted into one another, and that gold, therefore, could not be made from mercury. Today, however, as all are well aware, transmutations of the elements have been observed to occur, both spontaneously in radioactive disintegrations and when artificially brought about by electrical bombardment; and it is no longer considered impossible that gold may at some future time be made out of mercury. Originally, then, it was an accepted fact that transmutation occurred; subsequently it was an accepted fact that it could not occur; now we know that it does occur, though not at all as the old alchemists imagined.

These instances taken together show clearly the peculiar character of the changes which facts undergo. Their total content is conserved but their meaning is altered, sometimes slightly though often radically, by every fresh discovery. We may, if we choose, postulate an eternal substratum of possible experience in

the complete world of events; but what we call facts are not the elements of this reality as it may be conceived to exist apart from our knowledge about it — they constitute our knowledge about it and nothing else. When, therefore, facts change their meaning; when, as we say, they are reinterpreted; when the simpler of them which are the seemingly permanent elements of our experience enter into new complexes of relation in new ways and are thus thought about differently, then to the degree that they are thus affected, as elements of knowledge (which is what they *are* at any given time) they completely change. We must always realize this. When we think of facts as anything else than elements of this kaleidoscopic knowledge, which with every turn of the wheel of time changes color and figure so swiftly that its actually irreducible elements can never be certainly identified in the successive patterns it presents to our eyes, then we are not accepting facts for what thy are scientifically, but are merely theorizing about them, and usually to no definable purpose.

The chemistry of silver, which has already provided us with interesting illustrations of specific scientific facts, yields further information even more instructive. Thus far we have considered only certain details concerning the properties and behavior of this metal and its compounds. It is also commonly known that when the chemical changes which these compounds undergo take place in isolated systems — as,

for instance, sealed in glass — there is no demonstrable change in total mass; that from a given mass of silver the same mass of any compound is always obtained by complete conversion; and that by the complete decomposition of any compound, the original mass of silver, indistinguishable from the unconverted metal, is always recovered; that the several masses of different compounds obtainable by total conversion of equal masses of silver will, if these compounds react with another substance, completely convert either identical masses of this substance or multiples of such masses; and that by no known chemical process can a given mass of silver yield by complete reaction a smaller mass of any new substance. Furthermore, it is known, or inferred by analogy, that the heat evolved or absorbed in any of these reactions is equal to that absorbed or evolved by its reversal, and that this is the case whether the conversion be immediate or accomplished by any possible series of successive reactions. Finally, every chemist knows that silver belongs to the univalent group of elements in the periodic classification — that its atomic weight is the same as its equivalent weight — and that its atomic number is 47.

This second group of statements concerning the chemistry of silver differ from those previously considered in being more inclusive. The first of these, which affirms the invariability of the total mass of certain reacting chemical systems, applies not to one substance or process, but to many: it involves a much extended range of experience. Indeed, this particular statement might have been made more inclusive still:

it is, so far as it has been tested, a truth without exception, and appears to hold for all chemical reactions whatever. Furthermore, again within our experience, it is exact beyond the limit of possible precision in measurement. It is, in short, a perfectly general fact — what we call a law of nature; and may be stated, therefore, quite generally to this effect: that in no isolated reacting system is there ever any measurable gain or loss of total mass. This law is known as the law of the conservation of mass. In much early modern experimental work it was assumed without proof to be true: that is, very commonly in chemical reasoning it was unconsciously presupposed by the ingenuous, and accepted tentatively as a methodological postulate by the philosophical. It was first tested experimentally by Lavoisier toward the end of the eighteenth century, and was shown by him to hold, in the case of a few combustions, to about one part in ten thousand: later work by Landolt proved it valid for several reactions of different types to one part in a million or ten million. It has not been tested for every sort of process, but belief in its universality is justified by its complete consistence with a very large mass of evidence obtained in the exact quantitative investigation of mass relations in hundreds of thousands of chemical changes of great variety, conducted under widely different conditions; and while its exactitude according to this more inclusive evidence is not demonstrated with comparable accuracy, it is still thus shown to be superior to that of measurement. This very inclusive fact, or law, is one of the most precisely determined and completely validated of all scientific generalizations.

Its limitations, as above defined, are therefore of peculiar interest.

The statements immediately following, which refer to the mass relations in chemical change, may be made equally general though not equally exact. Thus expressed, they assert the invariability of the mass composition of all pure chemical compounds; that is, of substances which however prepared have under like conditions of temperature, pressure and so on (further necessary qualifications being here disregarded), the same physical properties — such as crystalline form, density, melting or boiling temperatures, specific heat. They assert, furthermore, the invariability of the ratios between the equally invariable combining masses of substances which, like silver, are unanalyzable. The last statement of this group, namely that a given mass of silver cannot yield by complete reaction a smaller mass of any new substance, explains what is meant by the term unanalyzable, and defines a chemical element. These laws are the fundamental generalizations of chemistry, and when fully expressed comprise the laws of definite and multiple proportions and of chemical equivalence. They were first established by Richter, Proust and Dalton at the beginning of the nineteenth century, and have since been repeatedly confirmed with increasing exactitude. Together they summarize the facts which support the chemical atomic theory, and are thus among the most valuable of all scientific evidences. In one sense only are they inferior to the law of the conservation of mass: they are less exact, inasmuch as their determination, unlike that of total mass, involves the preparation of pure ma-

terial, a very difficult task never perfectly accomplished. While the law of the conservation of mass is true to one part in a million or ten million, those of chemical composition are verifiable in the most favorable instances only to about one part in ten thousand.

The accompanying statement concerning heats of reaction refers to phenomena which illustrate another universal law which, like the preceding, is exact within the limitations imposed by uncertainty of measurement. This is the law of the conservation of energy, first enunciated as an inference based upon highly suggestive but inconclusive evidence by Carnot and by Mayer, experimentally demonstrated by Joule in the first half of the nineteenth century, and since then confirmed many times by elaborate calorimetric measurements of slowly increasing precision. An understandable statement of this generalization would involve digressions too elaborate to be attempted in a general survey. It will suffice to note the fact that, since its establishment involves the thermal isolation or very precise control of systems which change their temperature — one of the most difficult of all experimental problems — this law is still less exact than the laws of chemical combination: is true, probably, to about one part in five thousand.

The establishment of these general laws is typical of the supreme achievement of physical science. It is worth while, therefore, to remark their common character. They represent our most inclusive generalizations of fact, and are true within a range of approximation which is no greater than that of uncertainty in measurement. They may not be assumed to be more

exact than this; that is, they are not absolutely true: indeed there is good reason now to believe that they are only approximations to discoverable truth. Considering the atomistic structure of the physical world which is now demonstrated as fact, they are statistical laws: within regions sufficiently minute, we are now beginning to be suspicious that they may not hold at all. Theoretically, then, they are not only inexact, they are relative truths. Furthermore, inasmuch as none has been tested over the whole range of physico-chemical experience, they are, also, not certain even as inexact and relative truths: they are, with respect to their universality, only probable truths. The probability is very high, of course, but it remains a probability.

Such, then, are the ultimate results of the scientific search for truth. It must now be noticed, further, that generalizations of this degree of dependability are very rare indeed. The overwhelming number of natural laws are demonstrably inexact: in other words, their disaccord with the facts which they embrace is greater than that between the results of the measurements which determine these facts. This implies that the greater number of these generalizations are not fixed, but changing. The changes which they undergo may be the consequence of successive restrictions of the range of their applicability, or of restatement and reformulation, or of both, to bring them into closer accord with the new facts which increasingly minute or extensive measurements bring to light.

An excellent illustration of this characteristic growth of natural laws is the history of the law of

Boyle, which states that at constant temperature the volume of a definite mass of gas varies inversely as the pressure. In briefest outline, this law, which is of the greatest theoretical consequence, being one of the foundation stones of thermodynamical theory, underwent the following changes. It was stated first in a form equivalent to that here given, as descriptive of the behavior of air over a pressure range of from about four atmospheres to a thirtieth of an atmosphere, and was exact within measurement error, or to within one part in a hundred or more. It was later found to be equally well descriptive of the behavior of gases other than air, but was soon discovered to be inapplicable to gases near their temperatures of condensation into liquids, or as we commonly say, to vapors. Thus it was first made more inclusive, then its range was restricted. Further and increasingly precise measurement then showed that easily compressible gases were more compressible than the law indicated at low pressures, and less so at high pressures. The later experimental control of high pressures and low temperatures, by vastly extending the range of experimentation, exhibited gross exaggerations of these irregularities, but showed in the end that they were characteristic of all gases; so that although it was now apparent that the original law was applicable to no gas excepting within narrow pressure ranges at relatively high temperatures, it was evident that the variabilities themselves were all of one type. The original law had thus been shown to be a rough approximation except within a sharply restricted range of conditions, but it was simultaneously indicated that a reformulation might

preserve its generality. This was first attempted by applying to the volume factor certain specific constant terms of correction, one for each gas, of such magnitude that in every case the new formulation was brought as closely as was possible by such means into accord with the data. This procedure was suggested by the molecular theory of gases, then well established, and thus given physical meaning. The terms of correction, briefly, were supposed to represent the volumes of the gas molecules themselves, so that when they were subtracted from the apparent volume, the difference represented the vacuous space which could be diminished by pressure. The law thus modified was even now inexact, however: its formulation was therefore further elaborated, again on the basis of theoretical considerations, but more hazardously; this time by applying a term of correction to the pressure factor which represented somewhat hypothetically the mutual attraction of the molecules and its change with varying volume, the effect of which had theoretically to be added to the external pressure in order to represent the actual tendency of the gas to contract. The law then fitted the facts more closely, indeed quite satisfactorily, though its discrepancies with various data were still measurable.

This formulation still remains theoretically unmodified, although its further arbitrary numerical alteration might make it more accurately representative. Purely inductive formulations which are suggested in this way, or others more simple which merely summate numerical multiples of different powers of the variables involved, are commonly used in physics when-

ever no simple regularity of behavior is apparent in analogous phenomena, or when for purposes of calculation it is useful to have at hand a precise though unilluminating general representation of any particular group of facts. It is clear that by the ingenious employment of a sufficient number of terms of different orders of magnitude they may be made very precise indeed. Such formulations, called in the narrow sense empirical, are seldom referred to as laws, unless with reference to phenomena other than those to which they are, so to speak, cut and fitted, they appear to have theoretical significance; but they not infrequently yield suggestions of this character, and thus promote research. In the absence of such significance, they are of course without meaning, since often it is possible to devise several which equally well would serve every given purpose. With reference to the present case they happen to be of no great value excepting technically. It is now believed, indeed, that molecules are elastic, and therefore of changing volume; and that the laws of their mutual attraction are not yet known.

If this illustration be taken as representative of the greater number of generalizations of fact — and this is justifiable — it will be clear that with the growth of knowledge these generalizations change both extensively and intensively, that theoretical speculation enters into the process of their revision, and that as they become more exact they also become more complicated. This last observation indicates that the order of nature in which nearly all of us believe is not so simple as the uninformed are apt to suppose. On the

basis of empirical evidence alone the most plausible hypothesis to make concerning it, if we grant the premise at all, is that this order is of a character which would make the mathematical expression of natural laws complexes of endless series of terms. It is of course possible to conceive that our chosen correlations of fact are not happily selected: that a different carving out of our experience might yield laws more simple. Cumulative evidence, however, is against this supposition. As already remarked, attempts at the novel correlation of simple facts of any kind invariably lead back to the acceptance of those of common sense as the most stable and fertile. Moreover, the ease with which wide ranges of experience in separate fields have been brought together and unified without changing essentially the schemes of their prior generalizations indicates at least that any such imagined scheme of thought would have to be built up out of elements other than the simplest facts we know: in other words, that it would probably involve a revision of our simplest acts of cognition. Of course, this inference is not certain, but nothing is certain. Contemporary physics, which is considerably embarrassed theoretically just now, is already beginning to revise the most elementary postulates of common sense; and it is impossible to tell how far this may lead us toward actual transcendence of present experience. Meanwhile, however, our general atomistic picture of the world, which being completely consistent with the rest of our present knowledge is as true as anything can be, indicates that the complexities of natural laws are not due to great diversities of type in physico-chemical

changes, but to the superposition of a very few types of regular behavior in systems of different orders of magnitude — molar, molecular, atomic and electronic — each of which affects that of the systems of higher order with variability. This fascinating picture invites further comment, but one must at some point forbear. It is enough for the present to realize that complicated natural laws may be analyzed by atomistic theory, and thus again made simple. The simplicity thus arrived at is not always apparent to anyone but a person who, like the mathematician, is quite unembarrassed by endless permutations and combinations of effects; but it exists, nevertheless, since however complicated it may appear in detail, it yet may be represented by equations of general relation which may be understood without great difficulty. There is, at any rate, an atomistic order in nature.

It is interesting to notice also in this connection that, considering all this evidence, our grossly approximate generalizations may be quite as significant, quite as representative of types of behavior, as the most exact. This is a consoling thought, particularly to the practical mind; for it will be realized that the types of generalizations here cited are those which are the most sharply defined of all. Beside these quantitative laws, there are many others which are wholly qualitative in character, and among these are many comprehensive descriptions of general processes which cannot yet be developed in detail on account of the complexity of the phenomena they summarize. Such generalizations are characteristic of geology, biology, and psychology; but they occur in all the sciences, and are of

course evidences of the limited scope of our factual correlations in all fields, as empirical formulations and classificatory descriptions are evidences of our very extensive ignorance.

The history of the periodic classification of the chemical elements, which has been mentioned with reference to the facts concerning silver, gives point to these remarks, and suggests that our hope of finding theoretical meaning in our rougher generalizations is justified by experience as well as by plausible conjecture. This classification was originally an imperfect table built up piecemeal, which exhibited very clearly the similarities between the properties and chemical behavior of the elements and their compounds. It was never wholly quantitative, and never more than partially inclusive, for there were always many exceptions to the rules which were derived from it, and with the growth of knowledge these exceptions multiplied themselves. None the less, it was called the periodic law; not only because it proved itself, despite its imperfections, an amazingly effective instrument of prediction, but because it revealed for the first time certain fixed relationships between the properties of all the elements taken together, which, though only imperfectly definable and interpretable, seemed to indicate some sort of similarity between them, and supported a long-cherished hope (which little other evidence encouraged) that they were modifications of fewer primary substances, perhaps even of one ultimate form of matter. Very recently this hope has been suddenly realized. We now know that the atoms of the elements are themselves compounds of electrical corpuscles;

and the similarities of elementary substances may therefore be defined with some approach toward exactness and with very high plausibility in terms of the structural relationships of their atoms, as the similarities of compound substances may be represented by those of their molecules. The periodic law, to our surprise and delight, is thus becoming minutely quantitative, and summarizes, along with a great wealth of knowledge still uninterpreted, our most exact information concerning the ultimate structure of matter. It is this information which is brought to the chemist's mind by the statement that the atomic number of silver is 47.

These illustrations of natural laws make it clearly apparent that every characteristic of the simple facts which common sense takes for granted and of those which science uses as the elements of her more careful synthesis of experience, must be attributed also to the most inclusive generalizations. Facts may be of any magnitude, but all are essentially alike: in every order they are of varying inclusiveness, exactitude and probability; and whatever their scope and significance, they are in process of constant change. Throughout the entire range of our knowledge, everything is in a state of perpetual flux.

This flux, however, is not the flux of birth and dissolution, of coming into being and going out of it. Facts come and go, but their total content is conserved. Fact, which is coercion, persists; and even its

constituent elements more frequently change color than disappear. They are seldom completely lost, though often by disruption, combination, redistribution and metamorphosis, their residua may be effectively disguised. All this means, of course, that it is the way in which we describe our vast complex of compelling relations which changes; and this obviously is because experience is continually in process of elaboration, so that the terms of our description must likewise be continually altered in order to embody, in a persistently consistent scheme of thought, new subtleties and corresponding correlations. The instability of these correlations, meanwhile, is becoming less, and the broad outlines of the scientific system not only more clearly defined, but more persistent. New knowledge continues to modify the outline of our world picture, often in startling ways, but its composition is beginning to take on the appearance of permanence. It is hazardous to attempt the interpretation of this phenomenon, yet difficult to resist the temptation to do so. It may have the profoundest significance — but this is not a scientific problem. Our analysis of the nature of scientific fact permits us to see more clearly the nature of the mystery which confronts us, but however far we might carry it, we should never find a clue to final truth. The profoundest thinker of us all is, as Newton described himself, like a little boy who picks up shells upon the seashore, and gazes uncomprehendingly across the limitless ocean. Meanwhile, however, our knowledge of that which is comprehensible, our knowledge of phenomena — our science, grows: not like a

crystalline aggregate, by the precipitation, partial dissolution and redisposition of invariable elements of fact; but like a species of organism, by the continual proliferation, absorption, destruction, regeneration, and readjustment of its elementary parts, in functional activity; and at longer intervals by variation and mutation, approaching perhaps a final stability of form. The analogy is imperfect, but its imagery may serve. Not impossibly, it is something more than an analogy. Scientific knowledge reflects the effort which produces it, an effort born of the struggle for life: it is vital; organized.

III

THE ELEMENTS OF THEORY

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It remains, to complete this survey of the scientific habit of thought, to consider in an equally general manner, not the elements of scientific knowledge, but the broad outlines of its theoretical organization. In the preceding discussions it has been impossible to avoid referring to the synthetic correlation of general facts, and this has naturally led to the incidental consideration of certain theoretical ideas. This anticipation, however, will not diminish the possible value of a brief methodical review of the whole matter, which even to the extent that it is reminiscent ought, like any such treatment, to be clarifying.

For the proper understanding of the scientific scheme of representation, it is first of all necessary that the fundamental similarity of all the conceptions which are interwoven and not infrequently blended in its making, be fully recognized. It is customary to distinguish these as facts and laws, theories and hypotheses; and the definition of these terms frequently receives a surprising amount of anxious attention among students of science and others. Discussions of this matter are usually encumbered by the presupposition that law and theory are fundamentally different in character; that a natural law is not a law at all, properly speaking, since it is not mandatory;

that facts alone are really true; that hypotheses are treacherous, to be avoided whenever possible — and so on. It will be apparent to anyone who has followed the preceding exposition that arguments of this sort are largely academic, not to say scholastic. They usually arise among those who have become impressed with the tentative character of scientific inference, while yet demanding the comfort of final truth; and who in the first glow of critical enthusiasm wish to tilt for themselves against the traditional windmills of Greek philosophy and eighteenth century deism.

A fact has been defined. It may be of any scope: if it is very inclusive and, particularly, if it describes some regularity of process, it is called a natural law. This word *law* is misleading only to those who invariably associate the idea of law with that of a lawgiver; its connotation of coercion is legitimate enough, and its common use to mean a general fact appears to be as justifiable as the employment of any other word in its secondary signification. An hypothesis is an inference of the same essential nature as a fact, which of course is itself an inference. Hypothesis, however, is an inference based on knowledge which is insufficient to prove its high probability. As the known complex of relations which it coördinates consistently with the rest of relevant knowledge becomes more inclusive, hypothesis rises to the dignity of theory: when this embraces all relevant knowledge, it becomes law. There are wide differences exhibited among hypotheses, theories and laws, but they are, speaking generally, differences of degree and not of kind. The contrary might be supposed if natural

laws were demonstrably exact and final. This, however, is not the case: all but a very few laws, as has been shown, exhibit inconsistencies with experience which are greater than those caused by uncertainty in observation; so that, consequently, by far the greater number have been revised or are in process of revision.

The continuity of the transition from hypothesis to law is exhibited by many historical developments. The heliocentric hypothesis of Heraclides, for instance, according to which Mercury and Venus revolved around the sun which in turn revolved around the earth, became a theory with Aristarchus who, presumably upon better evidence, showed that the phenomena could be saved by assuming consistently that all the planets revolved around the sun. This theory was revived and probably much improved upon by Copernicus, whose constructions were in satisfactory accord with a wealth of more precise observations; was made ten times as exact and also mechanically interpretable by Kepler, who represented the planetary orbits as simple ellipses; and, properly speaking, became a fact with Newton and his successors, who, in demonstrating the law of gravitation, explained it by mechanical principles established by experiment. What is now the law of gravitation was, when Newton first conceived it, an hypothesis, which was so roughly confirmed by the one test to which he subjected it that he laid it aside; during his lifetime it was only a theory, though an exceedingly promising one; and it required the combined genius of the greatest scientists of Europe, by a century of labor, to demonstrate it as a law. The atomic hypothesis of Leu-

cippus, revived and defended in modern times by Gassendi, became a theory with Dalton, who showed its consistence with the laws of chemical composition; a better one with Berzelius, who replaced the arbitrary assumptions of Dalton's theory by inductive inferences; and in our own day it has become a fact. The alchemical hypothesis which postulated the essence of sulphur as an elementary constituent of inflammable substances, became with Stahl the phlogiston theory, which made the hypothetical principle of inflammability explain many other sorts of chemical changes besides. A mathematician, even after the invalidation of this theory by Lavoisier, might still have interpreted it as a fact, by identifying phlogiston with negative oxygen: but interpretations of this character, common enough today, met with no favor among the hardheads of the eighteenth century, able mathematicians though many of them were; for unlike ourselves, they were completely imprisoned within the world of events, where positive-negative relations exist, but not negative substances all by themselves.

The last two illustrations suggest the sense in which hypotheses are most sharply differentiated from general facts, or laws, in the scientific mind. When a correlation is based upon a conception which is purely imaginative, such as atom or phlogiston, it appears to be qualitatively different from those correlations, equally bold perhaps, the terms of which are facts. This distinction may be defended. It applies, however, only to one type of hypothesis, as the above illustrations show; and the histories of the atomic and

phlogiston theories suggest that it is not very significant. Indeed, it is quite evident that the conceptions of atom and fire material — like the equally imaginative conceptions of light corpuscle and ether wave, caloric, electric fluid, protyle and benzene ring, *horror vacui*, entropy, proton, vital force and entelechy, monad, devil and ghost — are all inductive inferences from experience which, like the ideas of mass and energy, derive their several degrees of reality, which is to say their credibility, from their consistence with the rest of experience and from this alone.

This interlude concluded, it becomes possible to study the scientific synthesis, without being bothered by the embarrassing intrusion of irrelevant considerations, for what it is: a system of correlated ideas of similar derivation and various degrees of probability, in terms of which our complicated experience is at the moment most consistently and intelligibly describable. It will be convenient to study these ideas primarily in their subjective aspect, for this economizes thought by rendering its terms more precise. This attitude is what we commonly call the logical. It is worth while, however briefly and superficially, to examine it, particularly with reference to its genesis; for thus we may exhibit, sufficiently well for all ordinary purposes, the relation of logic and mathematics to the natural sciences. This done, the theoretical development of them all may be characterized in general terms, whereupon their conceptual structures which,

interlocked, produce the great framework of our scientific representations, may be described in a manner such as to recall their now generally familiar outlines.

The first essentials of constructive thought are clarity and precision in the use of words and other symbols, which are the coinage of our intellectual exchange. Each word represents a fact of some sort — a thing or a notion, a process, an aspect or attribute of any thing, notion or process, a relation — and we call them nouns and pronouns, verbs, adjectives and adverbs, prepositions and conjunctions, accordingly. But they may represent not one thing or process or relation alone, but many at once, grouped together inductively by some common character or characters. These collective words are necessarily more vague than those which refer to simple facts specifically, and the more inclusive they grow, the vaguer they become. The series: Jane, cow, mammal, vertebrate, animal, organism, object, fact, being, illustrates this admirably; the name of a particular cow, Jane, is unambiguous; the term Being is so strikingly lacking in definable content that for a century or more it puzzled the keenest of all the Greek philosophers. Faced with the difficulty of assigning clear meaning to collective words, common sense instinctively, and science consciously, adopts the device of making such words indicate specifically the common character by which the group to which it refers is most sharply and usefully distinguishable from others. The words mammal, invertebrate and organism give evidence in their literal meanings of the employment of this

device. Such words, and particularly those which are both highly general and sharply specific in the sense here noted, we call abstract, since they represent immediately, not whole groups, but selected or abstracted aspects of these.

The greater number of our scientifically useful words are, for reasons which are evident, abstract. It therefore becomes a very important matter to see to it that these, and together with them all which are used in any honest thought, are unequivocal. This is the primary business of logic; it was, in fact, its first historical concern. But the study of words immediately involves, and actually centers upon the study of their relations. All words derive their only clear meaning from their context: that is to say, from the propositions in which they occur, just as the aspects of facts to which they correspond have significance only in the facts themselves. The precise definition of words, therefore, compels the analytical study of successive processes of abstraction and leads, by comparisons which reveal general types of relation between them, to the ultimate study of propositional forms alone. The first stages of this study are familiar to us all: they are made unforgettable by our youthful anxiety regarding the consequences of all A being B and all B being C at the same time. Similar problems, repellant yet fascinating, the obvious answers to which acquired such wonderful dignity in Latin phrase, introduced us to the inexorable discipline of formal or deductive logic: the science of "hard words," which makes it possible to describe and elaborate — by the use of invariant symbols and thus with

arbitrary but illuminating exactitude — the types of inference which are approximated in instinctive thought, whenever it is attempted to develop the implications of simultaneously applicable statements. Its generalizations are known as the principles of deduction. Granted the fixed and unambiguous meaning of terms, these principles are perfectly consistent in their application to all conceptual relations, and are in this sense universally true. By means of them, all imaginable permutations and combinations of fixed ideas may be worked out by machinery, mechanical or symbolic; and by these routine processes — this is the real importance of logic — attention is directed to implications which are missed in common thought, and the mind becomes capable of dealing with complexes of relation far too intricate to be directly conceived.

The possibly tremendous value of this machinery in scientific investigation is obvious, since by its means the full implication of any general idea may be thus developed almost without thought. Its utilization by science is, however, attended by certain risks which arise from inadvertence. In its full rigor, formal logic applies only to fixed and unambiguous — in a word, to invariant ideas. Now the ideas which are the criteria of judgment in natural science are representative of facts or factual coördinations; and these are all in some sense not only approximate but approximate in different and in changing degree. In order safely to apply the laws of deductive logic to such ideas, it is necessary for the scientist to carry his world of fact about with him, and to keep it constantly

before his eyes so that he may be aware at all times of the discrepancies between facts and theoretical conceptions, and capable therefore of interpreting correctly every mirage of thought. His simple method is to use each conceptual generalization — general idea — as a simplified *pattern* of the factual generalization to which it corresponds. With reference to this pattern, which defines, let us say, some type of natural process, he now describes the actual phenomena, noting as precisely as possible their variability, individual or collective, from the perfect regularity represented by the pattern. The pattern idea thus serves as a standard of reference, a norm; and natural irregularities of behavior are studied and evaluated — precisely measured if possible — as divergencies from this norm. This done, it is then possible without danger to employ the principles of deduction in developing the pattern, providing that the concurrent changes in the divergencies be kept in mind, so that any deductive inference which may be found useful shall, before it is employed, be properly conceived as another form of pattern merely, in similar relation to the phenomena, which carries with it a fringe of divergence which may or may not be the same as that of the original. Without analyzing the matter further, it is evident that the divergencies themselves thus become secondary norms; for the deductive development of these divergencies presupposes that they suffer alterations of undetermined internal relationships, which alterations are of a character similar to those which affect the primary pattern. This will not be the case, of course, if they

represent superimposed effects which change according to other laws. The study of these divergencies from regular behavior thus becomes a most fertile kind of labor, and in certain sorts of investigation the source of all significant discovery. By this method of procedure then, the natural scientist may take advantage of the simple routine processes of deductive logic in developing his general ideas, without losing sight for a moment of the degree of their approximation to fact. He thus minimizes his risk of error in inference, extends its intermediate range at will through unthinkable complexes of relation, economizes thought to an unimaginable degree, and at the same time, in his precautionary measures themselves, discovers an effective means for the progressively minute analysis of superimposed effects.

Another advantage is thus secured, obvious enough and already suggested, but deserving of further notice because it is so frequently underestimated. It is commonly affirmed that deductive reasoning, since it merely develops the implications of general statements, yields nothing new. This, of course, is merely an awkward and misleading assertion of the fixed interdependence of logical relations; its futility may be exhibited by its perfectly legitimate generalization to this effect: that science yields nothing new, for the reason that just as all the logical implications of a general idea are latent in its first expression, so all natural laws are latent in the undifferentiated complex of pure experience. It is permissible to say these things, but they are mere verbiage. In common sense and science, newness consists in becoming known.

The logical development of any idea yields new knowledge, or that which becomes new knowledge when its consistence with the rest of experience is established. The mind does not immediately grasp all the significant implications of general facts; and the logical revelation of these is discovery. If the relations thus brought to light have been otherwise demonstrated in advance, then logic has revealed nothing new except the correlation of diverse experiences; but even this is frequently of the highest importance. If they have not been thus demonstrated in advance, then logic has yielded something completely new. It makes no difference that this might have been discovered by independent experimentation; usually it is not so discovered, and if it were — it is a matter of practical consequence to note the fact — this would frequently mean much wholly unnecessary waste of effort. It may be worth while to cite a simple case. In uniformly accelerated motion, instantaneous velocity is proportional to the time elapsed. It follows logically, and may be demonstrated by simple algebra, that the space traversed is proportional to the square of this time, and also to the square of the instantaneous velocity. These demonstrations are discoveries, for no mind immediately grasps the truth of all these facts when one alone is demonstrated. It might often be possible to demonstrate them separately by experiment, or by trial rearrangements of the data of one experiment; but this would be, comparatively, very slow and tedious labor, even though in the end it were complete. It is clear, then, that logical processes of inference, wherever

they are applicable, directly add to our general knowledge a wealth of fresh information, attainable with the greatest ease and therefore quickly; which marvelously enriches our understanding of every generalization by permitting us to view it in several aspects at will, and thus provides the most fertile of suggestions for the further progressive organization of our thought.

The foregoing considerations are so important in defining the general character of scientific theory that it will not be profitless to emphasize the more significant among them by restatement from a slightly different point of view. The task of the scientific theorist is to coördinate, by successive correlations and as extensively as possible, the whole of our exact knowledge in a network of mutually consistent ideas. From a theoretical, that is to say from a logical point of view, it makes no difference in any scheme of thought, excepting for convenience, what existences are chosen as primary; for any conceptual plan, being one of relations merely, may be developed from any starting point whatever. Logic and mathematics, the sciences of pure relation, enjoy complete freedom in this respect. This is denied to science as a whole, that is to natural science; for its conceptual superstructure must be built out of given relations between facts. It is the theorist's business to make this superstructure true, that is, consistent; and this means logical.

Now, whatever his task may be, the theorist's first procedure is to select invariants: unchanging terms of discourse which alone can serve the purposes of exact reasoning. In pure logic and mathematics this choice

is wholly free, for numberless invariants abound in pure thought: a mere act of the will can bring them into existence, and thus invariance is absolute, if one is careful. In natural science, obviously, the case is very different: there are numberless facts to be sure; but the simplest of these are already more than mere terms of discourse, inasmuch as they express various sorts of relations, among which those that exhibit complete invariance are very rare. Few scientifically useful facts have been determined without possibly significant disagreement; their simplest relations are very seldom describable with a precision equal to that of observation; and new experiences, moreover, may change the character of any fact at any time. These circumstances, however, do not in the least embarrass the theorist. It is his habit first to select fact-relations which promise to be most useful for clear and if possible for simple synthesis. An immediately fertile choice is usually the product of a keen intuition which is developed only by prolonged study of his subject matter, and which, probably, is the result of various subconscious experiments in thought, based upon the customary correlations of common sense which are themselves the products of countless similar but cruder ventures sifted out in experience. Occasionally, however, a fertile choice is as we say accidental; which means that it is guided by practice alone. And frequently the theorist's choice is not a happy one. Its insufficiency in revealing significant or important relations between facts (by which we signify relations useful in the clarification of thought) is sometimes discovered at once, sometimes only after

extensive development. In extreme cases of the latter sort, one witnesses the complete metamorphosis of natural laws and theories.

In the development of his scheme, the theorist, having selected his probably significant facts, treats them as invariants, although he is well aware that really they are not so. It is the theorist's habit, when approximate invariance is discovered, to describe it as if it were exact; then, its variability having been, itself, more closely determined, to describe this similarly and to modify his formulations accordingly. This procedure is endless. It seldom yields a description which is exact within actual experience, and when this occasionally happens it is usually the case that subsequent discriminations more precise betray new variability. It is thus impossible to assume that there exists any absolute invariability. None the less, each stage of the theorist's description of things-in-relation is stated as if it were exact, and is thus made susceptible of logical or mathematical elaboration: meanwhile, however, it must be interpreted as approximate merely, within a defined range of real variability, which itself will be determinable with different degrees of precision according to the minuteness of observation. In very close work, discrepancies between the data yielded by comparable determinations may be of a magnitude which equals or even exceeds that of the variability which is being investigated. Whenever this happens, appeal is made to the mathematical theory of probability, itself the remote development of inductive inferences from simple experiences, to distinguish real variability from

error of observation. In these instances there is great hazard in interpreting the results, especially since it is seldom possible to know whether the simplifying assumptions which make a theory of probability possible are relevant in the case examined. Similar considerations apply to the mathematical development of any determined relation, since in deductive processes errors may be magnified, neglected terms rendered significant, hypotheses multiplied and so on. In careful scientific work, consequently, no deduction from determined relations is accepted as a necessary consequence of these until its consistency with other directly determined relations has been found by trial; and if such checking is impossible, as in the study of minute variability, the results are held by all but reckless enthusiasts to be highly hypothetical.

These considerations, which are wholly general and apply both to the simplest and to the most involved of all scientific studies of relation, are sufficient to show what is meant in natural science by the terms *definite* and *invariable*. In thought they have exact signification, but in experience considered as a whole, almost none; and if ever, then provisionally only. Thus, though there may be in logic and mathematics relations which are the necessary consequences of other relations, this is never the case in science as a whole. There is in experience at large no final authority in deductive reasoning, because its premises are always inexact. In thought we may say that A is B, that B is C, and that therefore A is C; but in experience we may only say with particular qualifications, A resembles B, B resembles C, therefore A is

more or less like C, and so with any other type of reasoning. Every statement of relation is either the direct expression of an observation or of an inference derived deductively from some such statement. If it is an inference it must always be verified by its accord with other observations: its definiteness and invariability in the world of events may never be safely assumed on logical grounds alone.

These general considerations lead naturally and directly to the systematic study of typical scientific procedures in the organization of knowledge, all of which are logical. It would, however, be improper to abandon even a superficial survey of logic itself without reference to its higher independent development. This powerful engine of research is something more than the instrument of natural science. It has become, especially in recent years, a self-sufficient discipline of stupendous dignity, which arrogates to itself the unqualified title of Science, and disputes, with natural science and theology alike, the meaning of truth. In no general discussion of scientific theory is it permissible to ignore the influence of this logic. Its scientific no less than its metaphysical pretensions challenge the very premises of skeptical empiricism and pronounce its methods, which are those of observation and experiment, superficial and essentially unphilosophical. Its doctrines are, in fact, the subtlest and most vigorous expression in our day of that habit of thought which by one set of formulations or another

has set itself, ever since the time when Plato first gave it intellectual definition, in direct opposition to the empirical development of knowledge, and more frequently than not with complete success. A thoroughgoing discussion of the scientific issues which are raised by this philosophy would here, quite obviously, be out of place. A brief consideration of some of the more important of them, however, will serve two useful purposes. First, it will define with greater clearness the theoretical attitude of the natural scientist, and will help to mitigate the confusion of thought which the logician's use of the word science to mean logic alone has made too commonly prevalent. Secondly, it will provide a convenient opportunity for the brief discussion of various questions of general theoretical import which will elucidate further certain important details of typical scientific procedure. This having been done, a single illustration of this procedure will probably suffice to recall and summarize all previous arguments, and to present the theoretical investigator, not as the mysterious magician of popular imagination, but as an understandable human being whose ways, though strange, more closely resemble the common ways of common work than do those of any other specialist.

Unfortunately it is impossible to discuss any details of the higher logic in terms of common speech; for the most elementary exposition of its simplest concepts leads us at once into the icy solitudes of pure thought — a region even more dangerous than its adjacent wilderness of epistemology — where vital fire burns low, and words freeze upon the lips in frost patterns

of strange and inexpressible symbols. Its general character, however, may be described in language.

The unambiguous definition of collective terms, as has already been remarked, leads at once to the study of their relations, which is impossible excepting by the analysis of successive processes of abstraction. It is soon observed, as the comparison of these proceeds, and retrospectively it is recognized as inevitable, that to distil pure invariants from the chemical mixtures which are the terms of common speech, that is, from natural concepts, is quite impossible. Natural concepts are, in fact, merely complexes of natural relations; and when abstraction is carried to its bitter end, they vanish. Thus it comes about that, ultimately, logic becomes the study of relations only. It reduces language, that is to say, to prepositions and conjunctions; and since it must still possess existences between, among, by, from, before, with and upon which the relations thus designated subsist, it postulates a multitude of Its, the unanalyzable and indistinguishable sub-electrons of pure ratiocination, which are truly invariant. But the relations which are represented by common prepositions and conjunctions, being elements of common experience, are themselves variable, not to say Protean. These also, therefore, are analyzed into simpler relations; and since they may not without confusion be represented by known words, nor with convenient simplicity by new ones, they are represented by symbols. Thereupon all language disappears, and we discover ourselves in the presence of symbolic logic, or of higher mathematics, which is its simplest exemplification.

So far, we are upon solid ground. The naïveté of our own untechnical speech must not deceive us in this matter. This atomizing of thought is a process very familiar, in one aspect, to the natural scientist. When physics reduces all phenomena to manifestations of energy, the physicist is doing precisely the same thing. The further one proceeds with this analogy, the more complete it becomes; indeed it is ultimately apparent that it is not analogy merely, but thoroughgoing similarity — for the physical scheme is itself conceptual, and logical. Its customary terms, space, time and mass, deceive us: they seem existent in a different sense; and so they are, of course, being facts. But scientifically handled, space and time are atomized, like mass, and mass itself is one of those complexes of relation which, being variable, must be analyzed if we are to discover the invariants which are as desirable in physics as in logic. When we have decided upon them they will certainly be of the same family with the Its of logic. The atoms of Boscovich, prophetically, were such Its: centers of force, geometrical points. And meanwhile, the instrument of scientific analysis is mathematics, a kind of logic. This reduces all these reflections to tautology: but it is something to recognize a tautology. Of course, to the scientist, physical science, and more obviously natural science as a whole, is not merely logic; for its scheme of conceptual relations is restricted by the necessity of its close and complete accord with fact. Scientific theory then, though logical, represents something more significant than logic, inasmuch as it involves a wider range of consistency. It exists not in the world of thought

alone, but in the complete world of events; it is the conceptual aspect of a universal experience, which is something very different from conceptual experience alone.

These simple observations are sufficient to characterize in a general way the developed logical scheme of representation, and to indicate sketchily the manner of its incorporation in scientific theory. The shivering logical camel, whose proffered service once haughtily rejected has been found to be quite indispensable, now shares in closest intimacy the hospitable warmth of our scientific shelter. It will, at this point, be instructive to observe the manner in which he is preparing to revenge himself by crowding us out of it altogether. Our understanding of the situation will be assisted, in the first place, by an hypothetical diagnosis of his condition.

To begin with, then, it is apparent to every student of the subject that the logical habit of thought exhibits an unmistakable trend toward a sort of metaphysical dogmatism which is frequently tinctured with emotion of a distinctly mystical character. This tendency is so natural that one might almost be justified in believing it to be inevitable. The long-continued and infrequently interrupted study of absolutely invariant existences exercises a powerful hypnotic effect upon the mind. As in other intense activity, the individual becomes unconscious of all experience save that which immediately engages the attention; the self expands to include the whole of this, and ultimately is absorbed by it. This very significant phenomenon has been remarked before. With the logician its effects are

peculiarly profound, for his intellectual concentration is extreme; and the world which it separates from the rest of experience and makes the whole of being is a world of unchanging and apparently eternal order, the only Absolute which his cold intellect need not reject. A conviction thus establishes itself which finally affects the whole of waking thought: that in this experience one has at last discovered the eternal and ultimate Truth. Such convictions are nothing new, but this one is unique: it is not a product of desire nor of ecstacy, but of pure thought; and there is no man accustomed to abstract reasoning who will not in some degree appreciate its force.

As a consequence of this conviction, which appears to justify philosophically a very natural inclination, the logical theorist, when he interprets science, adopts as his sole criterion of judgment that form of logic which represents the consummation of his achievement: not the logic of common thought, which includes the experimental processes of induction and the deductive development of natural concepts, but the completed logic of pure relation which is known to us most familiarly in the guise of higher mathematics. Our philosophical literature is now enriched with various expositions of scientific thought as the logician conceives it; and all of these preserve intact the original characteristics of rigidly formal logic, refined and subtilized to such degree in a nexus of minutely analyzed relations, and so technically elaborated that very few metaphysicians and still fewer natural scientists can understand it at all. The world which this logic represents, unlike that of ordi-

nary logic, includes no growing ideas whatever: it is a changeless world of invariants in exact and absolutely static coördination. When, therefore, with reference to it, the logician attempts the explanation of scientific thought, he inevitably represents this thought as the partial manifestation or progressive revelation of an absolute and universal immanence; ignoring all factual experience (so far as this is possible) in an attempt to realize by ratiocination alone an eternal immutability.

This representation, obviously, is that of a metaphysic or religion; and as such is no concern of science. But unlike other systems of belief, it has been generated within the very body of science: the child of her impulsive youth, which demands nourishment and perhaps correction from its parent. More prosily, it is an outgrowth of scientific method, and reacts directly to affect the quality of scientific research; for since logic is the perfect exemplification of complete consistency, its dogma remains unmodified throughout the range of its influence. This influence is general: it is such as to change the temper and the tone, in a word, the spirit of scientific investigation; and by diverting the interest of the theorist into metaphysical channels, to retard the progress of science rather than alter its character. This is because the actual procedures of the discoverer are determined by the compulsion of fact; so that while they may be inhibited by growing indifference to fact, they cannot be altered in this sense without becoming infertile.

These statements must be somewhat developed later: meanwhile they make it apparent that the

logician's metaphysical convictions are a proper scientific concern. Even though from a naturalistic point of view, as here, they be interpreted as results of partial anaesthesia — analogous to the similar convictions which, as every hospital nurse is aware, accompany the partial anaesthesia induced by drugs or by the weakness of starvation or fatigue — they may not on this account be ignored. They give rise to scientific representations which are completely at variance with and directly opposed to those of the empiricist. To him science is knowledge of fact logically organized; to the meditative logician, this organization is all there is to science properly so called. The empiricist considers logic as a useful fragment of science; the logician looks upon science as a contaminated fragment of logic. To the one, the changing world of fact is basic, or preëxistent; to the other, a static world of invariable relations is preëxistent. The first, therefore, discovers approximate and mutable relations in a growing experience and uses the exact conceptual relations which they suggest as patterns, with reference to which he examines them. To him the principles of logic describe invariable habits of thought and are therefore laws of nature of restricted range, the application of which to the whole of experience is limited and uncertain, indeed arbitrary. But the other believes himself to be in possession of ultimate existences: concepts of relation which, themselves in relation, actually constitute a final truth, which science progressively realizes. To him, therefore, her correlations are not merely convenient and tentative procedures in the organization of a muddled primary

experience: they are partial revelations of an eternal, logical order which is ultimate.

It is very hazardous to proceed even thus far in an unprofessional attempt to elucidate the logician's philosophical position, for it is evident that it is capable of developments as various as they are subtle. The logical order, it is clear, may be postulated as itself the totality of existence, in which case change would be inexplicable; or as the totality of experience only, the problem of existence being ignored; or of knowledge only, its relation to experience as a whole being left an open question; or, this order may be conceived as one element of a duplex totality in which change is imagined as a spirit which moves upon the face of still and eternal waters; or change itself as a fateful process preordained and logically describable — and so on, whither only the metaphysician can lead us. All such conceptions have this in common: that they postulate a permanence and order in the natural world revealed by conception which science strives to actualize.

So much metaphysics, it must be confessed, is a commonplace of scientific thought itself, which is betrayed by behavior in research. The scientist habitually speaks and acts as if he believed he were discovering a preëxistent order: the order of nature; and his basic ideas, which are factual, present this order as immaterial. In the absence of this belief it is to be feared that much enthusiasm would be lost to research, and that scientific productivity would be correspondingly impaired. It is a heritage from the remote past when science, metaphysics and theology were one; ingrained

therefore in all spontaneous meditative thought; which cannot be advantageously dispensed with before curiosity is developed beyond desire, and experience compels suspended judgment. Thus the scientist's theoretical quarrel with the metaphysician and the theologian — and incidentally with this logician who represents them both — arises not from a criticism of their purpose, but from a criticism of their method, with which he is regretfully familiar, and calls that of hypothesis without verification. This method has led the scientist astray so many times in the past that upon cumulative evidence he judges it to be bad. Historically, its failures made him skeptical; subsequent caution made him empirical; later wisdom — logic itself, perhaps — made him pragmatic. So that even though he may not yet have attained the complete detachment of suspended judgment, he dare not pretend that an idea is true because he feels it to be so, or because it is clear, or for any other reason than that it is consistent with his complete world of action and of thought together — with the whole of experience. He fears, and wisely, what these others defy: the thunderbolts of heaven, which are facts. Something like this has been said before, perhaps more than once; but the reiteration may be excused, since here it emphasizes specifically the reasonableness of the scientist's refusal to discuss the plausibility, the beauty, or the wonder of the logical metaphysic, and the necessity of his insistence in judging it exclusively by the pragmatic test: the test of complete consistency in actual experience.

So much by way of commentary upon what one may

call, for convenience, the metalogical attitude of mind. It will now be instructive briefly to examine its dogma: if we are thus led into somewhat arid fields of argument we shall find them probably not quite as infertile as we might apprehend.

In its general or realistic form, this dogma asserts that all experience may be analyzed into concepts and rebuilt out of them. All that need be said concerning this allegation is that there is nothing in experience to prove it, and that so far as we are aware, it would make no slightest difference in scientific procedure whether it were true or not. In physics, and consequently in all natural science, we have been engaged for centuries with the attempt to represent phenomena of all sorts as completely as possible by logical, and particularly, by mathematical formulations; and without doubt shall continue to do so, whether or not we believe that in the end we shall thus exhaust experience. At present we are very far from doing this even in conception, and the cumulative evidence so far obtained unequivocally supports the negative conclusion that the richly vivid world of immediate sense awareness is not thus reducible. This hypothesis, therefore, has no demonstrable value, and would make no difference in behavior if it were true: it is therefore scientifically gratuitous and negligible, unless like certain other forms of philosophical realism it shall definitely postulate the universal existence of specific ideas. In this case, as the historical record shows, it would tend to encourage a disregard of facts by directing exclusive attention to the conceptual universals from which it would consider them derived, would thus

discourage inductive inference by the inculcation of antagonistic principles elaborated from its own unsubstantiated premises, and unless past experience counts for nothing would thus prove itself pragmatically false.

In a less general form the same hypothesis would mean that all knowledge is logical, or more explicitly, that science is logic and nothing else. This statement may be taken to mean two things, according to whether science is being considered as knowledge or as activity. In the present context, it may have both meanings: the logician's attitude, as it is exhibited in his writings, clearly justifies this. He believes first, that scientific knowledge is exclusively logical; second that, since this is so, the procedures of formal logic provide a sufficient and advantageous method for its theoretical development. Indeed, he is disposed to assert, and frequently does assert with some assurance, that these procedures, which have their root in the very essence of reality, provide the only proper method in philosophy; and he calls this, without qualification, scientific method. All this is in the literature. It is barely possible that he sometimes uses the word 'science' archaically, with deliberation; but he never makes this confession, and we are therefore privileged to interpret him as a contemporary. It is clear that his first contention — that scientific knowledge is exclusively logical — might, from the point of view of the natural scientist, be admitted without discussion, since it would make no practical difference whether it were true or not. On the other hand, to grant his second contention — that the methods of formal logic

are preferable to those we now employ in scientific theory — would mean to abandon or to prepare to abandon many of our customary methods in natural science in favor of his newly elaborated variant of the ancient dispensation; and this, it is to be apprehended, would make some difference. It is evident, therefore, that to the natural scientist the question of method alone is consequential. His pragmatic test, it is worth noting, eliminates not merely all metaphysical questions but questions of definition as well. Whatever existence may be, or experience, or knowledge, or logic, is not a scientific but a philosophical concern; the definition of these terms is, to the scientist, only a matter of convenience. It will be realized that this neglect is not evasion: these questions really do not enter into the problem of determining that universal consistency which is scientific truth; and in the present case, consistency in conception being granted, this problem reduces itself to determining the range of corresponding consistency in the world of action; that is, to a testing of the efficacy of a method. To the logician, on the contrary, it is important that it be established first of all that scientific knowledge is wholly logical; since otherwise, obviously, his method will not be generally applicable. It is convenient, therefore, to consider the whole matter.

The statement that all scientific knowledge is logical attracts us immediately by its evident plausibility. Our mathematical generalizations are, in their simplified pattern-forms, complexes of strictly logical relations, and are in extended logical coördination. The facts which they represent are not in such relation,

since their divergencies from the regularities represented by our formulations are not logically definable; but as approximations they may, as has been explained, be treated logically. With the growth of knowledge, moreover, these divergencies yield in increasing measure to more extended logical formulation and become less and less significant; and if, as we commonly suppose, there is an actual order in nature, it is not inconceivable that they may be thus finally exhausted. If, or when, this end is reached, therefore, such formulations will be logical in the strictest sense, both severally and in coördination. It must be acknowledged that so far as our present evidence indicates, these final coördinations would be exceedingly complicated; but granted an order of nature, the same evidence suggests that such complications are more than likely to be results of the superposition of regularities much more simple which, it is not impossible to believe, may be themselves expressible as similar compositions of few, perhaps very few, general principles. If this be the case, then ultimately all of these phenomena might be described by the deductive elaboration of these principles. This would constitute the complete logical organization of this range of our scientific knowledge: physics and chemistry, let us say, would then, as compendia of knowledge, be logic and nothing else. Actually this is the goal toward which our theoretical efforts in physical science are directed. Physics, on the basis of simple mechanical principles, is already thus organized extensively by mathematical formulation.

If now we consider, not the science of physics, but that of chemistry, which is forced from the outset to deal with phenomena more complicated and still more varied, we are impressed particularly by the variety of its conceptual correlations, which exhibit, at least to the casual eye, a still greater intricacy and subtlety. But these correlations, though many are quite as general and quite as precise as those of physics, are far less inclusive. Wholly different types of generalization here supplement the mathematical formulation and its analogue, the exact symbolic representation of chemical compositions and reactions. Such are structural formulae which represent diagrammatically and qualitatively the chemical relations of substances as these are revealed by similar behavior or interaction; and such are the classifications assembled in the great periodic table of the elements, which exhibits quite generally but loosely a mass of similarities which range from exact quantitative relations to mere analogies. These types of formulation are of the highest scientific value; but they embody few exact generalizations and are not represented by any logic of invariants, since their terms, many of which are of variable significance, are themselves unanalyzed complexes of known but inexactly defined relations. In biology, practically all generalizations are of this type, and their terms are still less definite. To realize how far removed from exact logical expression scientific generalization becomes in chemistry and biology, one has only to recall such conceptions as those of solution, catalysis, enzyme, anabolism, sensation, species, evolution. These and numberless similar con-

ceptions are quite insusceptible of logical definition, and derive meaning only from descriptions of the complete and imperfectly differentiated complexes of fact to which they refer. That they may be more sharply identified by certain simple characters provisionally selected as representative and then statistically correlated does not make them logical in the theoretical sense. Finally, in all fields of investigation, whenever phenomena are not susceptible to mechanical interpretation, a very large part of our scientific knowledge is quite uncorrelated excepting by analogistic classifications which are based directly upon the immediate data of perception. Such are in greater part the principles of chemical analysis, metallurgy, petrography, meteorology, physiography, anatomy, physiology, systematic biology, medical diagnosis — and psychology, which includes the study of those phenomena that generate the science of logic itself.

Scientific correlations, therefore, represent all degrees of conceptual abstraction, from the simple arrangements of direct sensory experiences by shifting similarities of various sorts to the elaborate mathematical formulations of behavior in the fixed terms of space, time and mass, which, in their application to all ordinary experience are strictly invariant. All of these correlations, moreover, are of comparable scientific importance: their exactitude is no measure of their usefulness in either thought or action. It frequently happens that generalizations which are inferior in a logical sense are more instructive scientifically; sometimes because they are more inclusive, sometimes

merely because they are more simple. This is true, also, among strictly logical coördinations; the rough simple approximation, if it will serve a given purpose, is always used in preference to its more precise elaboration. It is the problem which determines scientific preference in logic; not vice versa. Knowledge grows by a multiplicity of observations, by induction, by hypothesis and verification. As it becomes more minute it is more and more exactly correlated logically: the growth of scientific knowledge guides the growth of scientific logic. At each stage of development facts are coördinated logically as precisely as possible: this coördination summarizes the advance to this point, and stimulates further advances by the deductive elaboration of generalizations thus formulated. In brief, scientific knowledge, determined by successive discoveries of facts, constructs its theory as it goes. Its logic, therefore, is always retrospective.

These very patent evidences are quite sufficient to define the sense in which it is proper to say that scientific knowledge is logic and nothing else. If logic be taken to include not the formal processes of deductive inference alone, but its common sense approximation as well, together with the inductive trial procedures upon which the whole reasoning process is built, and the data of immediate perception which are the terms of its first correlations, then science is wholly logical. Philosophers are in dispute as to whether immediate sensory experience may properly be called knowledge, and thus put into the logical category: for various reasons it seems wisely cautious and certainly advantageous not to do so. There is general

agreement, however, that since all the rest of knowledge is homogeneous in character, the general science of knowledge, excluding the consideration of sense awareness, may legitimately bear a single name, and this may as well be logic as anything else, if we take care to avoid ambiguities of speech. But this is not the logic of invariance, by means of which the ardent theorist would reduce all science to a vast complex of fixed relations. The logic of induction and of commonplace deduction — all the logic the terms of which have content and are distinguishable — this logic is a logic of ideas in evolution, whose growth directly mirrors the growth of factual experience from which it is derived. It is, if you please, natural logic: the conceptual aspect of natural science which is the embodiment of its knowledge, the product of its activity, its retrospective mood. The other is *logica purissima:* the abstraction of abstractions, the ultimate product of successive refinements of natural logic, the logical essence so to speak; it is changeless, static, inviolate; believed to be transcendent and eternal. No science, strictly speaking, is logical in this sense, for all its terms, however simple they may be, have physical meaning, or at least the ghost of a physical meaning. It is only in the degree that scientific conceptions become, conveniently for a time, fixed and rigid, that they may assume this guise. At present science is very imperfectly logical in any sense of the word: its approach to the ideal condition being indicated by the very rare exactitude with which natural phenomena may be described by mathematical formulations.

To the realistic philosopher, whose conception of

logic is large and generously flexible, science is already logical. When all phenomena — chemical, meteorological, biological and psychological as well as physical phenomena — shall be fairly well describable in mathematical or other exact formulations the terms of which, though they still have meaning are not embarrassingly variable, then we shall be able to say without exaggeration that it is respectably logical from the point of view of the natural logician. But only when the terms of these formulations are devoid of all content, have no meanings, and are thus become indistinguishable Its, and when they fit the phenomena exactly and always, — when, in other words, all of our knowledge is thus frozen stiff in a network of eternally fixed conceptions — then science will be logical to the doctor of invariance himself, and everybody will be dead. A startling realization, but true: for thought is life, and life is change, and here there is no change. With the painting of life's last picture, science will be complete, finished, and done with; and the sole activity of our immoral souls will be that of fixed, staring and thoughtless retrospection.

This Nirvana, of course, is the goal of our scientific aspiration. Our human consolation, meanwhile, like that of our devout forefathers who similarly contemplated the Jewish heaven of a former day, is the secret conviction that we never shall arrive. The prospect is remote in any event. The final exhaustion of all discrepancies between fact and formulation implies a fixed order of nature. Were this not the case, the process of logical analysis would be endless: its impossible problem the completion of many infinite se-

ries of concepts. It is true that the completed infinite offers no difficulties to many of these logicians, but the majority of us are unable to rise above the intellectual acumen of Aristotle, who excluded it from science; and we are not uneasy in following his example, since no more than he do we find it in experience, excepting as a negative: as potentiality. The abstractest theoretical physicist never conceives the infinite otherwise than as a limit, as a something approached but never attained, which means the same thing. This makes us scientifically skeptical concerning the completion of the theoretical logician's task: all evidence suggests that the invariant logical order is, with respect to actual knowledge, itself a limit — no possible actuality but an ever receding and persistent potentiality at best. At worst it is not even this, for we cannot be sure that there *is* a universal order of nature.

This idea is the generalization of a conception which was begot by that fateful regularity of celestial motions which set the ancient gods among the stars and thenceforth pictured every recurrent process as a manifestation of the divine will. It is an idea at once scientific and religious. In its complete generality it expresses scientifically, not so much conviction as purpose — the purpose, frequently unconscious, to describe in simplest terms, and thus to think easily and clearly. The philosophical question as to how far this motive — by determining the manner in which we have differentiated our primary experience — is accountable for the order which we discover in nature, is one which, though it may not be here dis-

cussed, must not be disregarded. Judging from unanalyzed, common-sense experience, this order is not conceptual, merely, but natural. The evidence of natural geometry, of mechanics both celestial and terrestrial, and of atomistics is not to be denied. It will be acknowledged, however, that our extension of this postulate beyond the range of simple mechanical phenomena is highly hypothetical; even though, because it now embodies our very hope of understanding anything, it has become, so to speak, the first article of the scientist's creed. The planetary movements exhibit order, the stellar configurations and movements none, thus far. Terrestrial gravitative phenomena exhibit order, those of molecular systems very little excepting in the gross, although such order may be reasonably assumed; but we have imagined order within the atom, consistently with appearances, and hope for the best. The disorder of the chemical elementary masses has yielded at length surprising regularities; that of their chemical affinities none — which is why so many chemists are actually afraid of the word affinity. Meanwhile, thermodynamics, as viewed, so to speak, from the molecule, is pure statistics, like molecular and stellar mechanics and the sciences (optimistically so called) of commerce, longevity, and intelligence. Finally, everybody knows that there is no order whatever in the detail of many geological and biological phenomena.

It thus appears that our actual evidence of order in nature is rather slight. It almost seems that it is necessary to get some distance away from actual occurrences to discover order among them. There was more

order in the heavens before the invention of the telescope than afterwards; there is more order in the behavior of gases in bulk than in that of their molecules, more order in atomic numbers than in atomic spectra. None the less, all scientists postulate this order, although they recognize it as a very hazardous extrapolation of experience: many because it has remained their religion — a precious heritage from Chaldea and Greece; the rest because they know no other way to understanding. At the same time it is well to remember that if there be real order in nature, it is quite possibly not universal. Old Heraclitus, who has been mentioned before, saw in the dynamic equilibrium of the whirlpool the explanation of all apparent stability; and he knew that although whirlpools occur in rivers, the rivers are not wholly composed of them. A similar explanation might account for our molar mechanical phenomena. Furthermore, the fundamental criticisms which the biologist Aristotle brought against the atomism of the physicists who preceded him have never been contraverted. Mechanism does not explain the cyclic phenomena of life: the vitalist is still a redoubtable iconoclast, even if he has no constructive method. It is possible that our universe is growing, like an animal; that the world of fact itself, like our knowledge about it, is slowly changing. If so, our laws of nature altogether may be the coördinations of mere temporal cross-sections of experience. All of this, without doubt, and much more to the same effect will be found in the philosophies. It is not scientific hypothesis, but criticism: very good medicine for dogmatism, either logical or scientific; and perfectly

harmless to any good skeptical empiricist, however it may affect the logician of invariance.

This, then, is one reason for our secret suspicion that we may never know the Nirvana which science seeks. Another, in itself sufficient, is that invariant logic, believed to be transcendental and absolute, is really nothing of the sort. It has exorcised all the ghosts of meaning that haunt its terms, and has reduced itself to relations; but though it has minutely dissected these relations, their substance persists, and this is the substance of factual experience; for they are analytical expressions of conceptual relations which in turn are aspects of factual relations. As has been said before, it is impossible to exorcise fact. These relations, then — which are the elements of invariant logic — being parts of ordinary experience, change with the rest of it. Physical science, indeed, is at the present moment engaged in an experimental revision of the meanings of our basic common-sense conceptions of *when* and *where,* which appear to be no longer adequate to describe recent scientific experience; and the character of this revision is such as to suggest to the metaphysicians themselves the probable complete relativity of all ideas, and their impermanence as well. It is clear that the unqualified acceptance of this opinion as a working hypothesis would make skeptical empiricists of all philosophers. This, however, is not in human nature. We shall always, probably, be searching for the absolute, even though the more closely we seem to approach it, the more elusive it becomes. But meanwhile, we must write against the logician's postulate of final truth, as against all other transcendental postulates: not demonstrated.

Against this postulate, however, we may not write: impracticable. Although the logician's key may not unlock for us the innermost sanctuary of knowledge, it may yet facilitate our progress toward it, by piercing the walls of its protecting labyrinth. If our habits of thought have determined in any degree our categories of fact, then the logic of invariance, which most minutely describes these habits, may enable us to anticipate discovery by the application to our experience of a completed pattern of conceptual correlations which extends beyond its range, in place of the partial patterns we now employ. This would be the logician's scientific method. He would deduce particular correlations from the premises to which he has been led by the exhaustive analysis of our ideas, and thus discover unsuspected relations of perfectly general scope precisely as common logic discovers them within the range of experience. It is not necessary to believe with the transcendentalist that these deductions are Truth itself. From the skeptical point of view, they would be hypotheses to be verified: but it is easy to see that even if the accord between conception and fact within our experience were likely to justify nothing more than their plausibility, they might none the less become invaluable instruments for the guiding of conjecture into fruitful fields.

Logicians have already made a few attempts to develop their method, if not precisely with this end in view, at least with the purpose of finding perfect logical expression for some of our naïve scientific conceptions, which is, in effect, the first step toward it. Their results, unfortunately, are unpromising. In the first

place, it is very evident that the task is one of exceptional difficulty. The logician is secure in his world of pure relations; but whenever he returns to the world of fact, he appears habitually to forget some turnings of the path by which he departed from it. His processes of abstraction involve successive eliminations of numberless aspects of experience, which, before his results may be made applicable to fact, must be recovered, examined, and to the extent that they are essential to practical — that is to say, general — understanding, reincorporated. This synthetic procedure is evidently, in its entirety, an almost impossible undertaking. It is like the reconstruction of the wood-carver's block from the chips of his workshop, and that of the tree from the reassemblage of these with the tailings and sawdust of the mill and the brush of the lumber camp. Indeed, in the logical reconstruction of the simplest natural concepts, which alone so far have been attempted, it is evident to the scientist that essential parts are missing, having been carelessly rejected and then mislaid. We are reminded that

> " All the King's horses and all the King's men,
> Couldn't put Humpty together again."

In the second place, these reconstructions are not convincing simulacra, and certainly yield no clarification of productive (as distinct from purely speculative) thought. This is, logically speaking, a matter of no moment; but practically it very narrowly restricts — if it does not destroy — their imaginable utility. The analysis which yields us the totality of an infinite series of compound terms in place of a geometrical

point would probably make the simplest crystal structures very difficult to understand, and their mutual relations still more so. These difficulties could doubtless be much reduced by formal generalizations and intermediate formulations — manipulated without thought as in ordinary logic; but even then the superiority of such representations over those of geometry is not apparent. The matter need not be dwelt upon: it is sufficient to say that unless it be granted that some truth more profound than that revealed by customary scientific formulations is latent in these representations — and this may not be granted for reasons already given — their employment in theoretical research should await a more convincing demonstration of their possible usefulness than any yet afforded us.

It thus appears that the logic of invariance in its complex entirety neither summarizes scientific knowledge nor provides a superior method to justify its further scientific pretension. There is, however, a type of invariant logic without reference to which it is impossible, as we have seen, to discuss scientific method even in the most superficial way. This is the science of mathematics: one of the most effective instruments of research in the whole workshop of the investigator; his instrument of deduction, which yields precedence in usefulness to imagination and experiment alone. The extraordinary value of this type of invariant logic is undoubtedly due to its relatively extreme simplicity. In its elementary branches, which

establish all of its detailed procedures, it is merely the formal elaboration, with reference to the idea of order or initial arrangement, of the single conjunctive relation *and*: the most sharply clear of all our simplest concepts — more definite than *when* and *where*, the concepts with which it is primarily associated, and the only irreducible invariant relation that we know, which furthermore is universal. All this is a logical way of saying that mathematics is a development of the art of counting, the oldest strictly scientific technique: the recognition of which as the only invariable and the most exact of all universally applicable scientific procedures — and the embodiment therefore of the most fundamental of scientific ideas — made Pythagoras immortal.

It is unnecessary to discourse on the universality of the idea of number, since everyone has known from childhood that we may count whatever may be clearly distinguished either by perception or by thought; nor upon its extremely abstract character, since we may count all sorts of distinguishable things without reference to their qualities; nor upon its exactitude, which the schoolboy realized, who, when his correct solution of a multiplication was approved as very good, asserted with indignant vehemence that it was perfect! And to realize the utter simplicity of the whole mathematics of number it is only necessary to remind ourselves that the undoing of an addition is a subtraction, its repetition a multiplication; that the undoing of this is a division, its repetition, the raising to a power; and that the undoing of this is the extraction of a root: that the indicated performance of

these operations, made symbolic and thus substantive in thought, yields new types of number, devices of convenience which frequently puzzle the over-subtle — surds which symbolize the exact but incommensurable ratios of geometry, negative numbers which have factual existence only in relation to their opposites, imaginary and complex numbers which thus exist only in particular interrelation: that the actual performance of these operations, combined in various ways, is the whole art of arithmetic, and that the theoretical study of the complexes of relation which may thus occur — which covers the whole detail of mathematical procedure — is the science of algebra.

Arithmetic is explicit, concrete; it deals with particular numbers: algebra is general, abstract; it deals with relations alone, its terms may stand for any numbers and are distinguishable only by being different from each other; it is the invariant logic of the relation *and*. This algebra is, as has been implied, very inclusive and varied, having been developed originally by the investigation of many kinds of practical problems, and later expanded and organized by intercomparisons of the diverse types of numerical relationships thus revealed. It exhibits to the unfamiliar eye a rich profusion of general coördinations and derived routine procedures which give it the appearance of extreme diversity; but this is not the diversity of confusion. Whatever strange appearance its formulations may present, they embody but one logic, the logic of mathematical forms or types of numerical relation; and anyone familiar with the more general of these and habituated by practise to the fascinating trickery

of their conversion, may read the meaning of any algebraic process if he understands the meaning of its premises. With this single instrument the mathematician develops the implications of all his primary formulations: his logic is, therefore, the simplest conceivable, and for this reason the most effective imaginable for the clarification of thought.

On account of its essential simplicity, indeed, theoretical mathematicians of strictly scientific persuasion now sharply distinguish their science from the rest of logic; and justify this separation by deriving the meanings of their most abstruse conceptions, such as negative and imaginary numbers — conceptions which have caused and still cause the most embarrassing confusion of thought among the imaginative — exclusively from the relations of groups of whole numbers. Their methods of doing this are necessarily cumbersome, and are not readily understood off-hand; but the results are very important in a scientific sense, since they eliminate from consideration as wholly gratuitous a mass of tantalizing mathematical magic which has exasperated the intellectual world for centuries; and establish the whole science at last on a sound empirical basis, by demonstrating its derivation from counting alone.

Beyond the organization of algebra, the whole development of mathematics, so far as it concerns the natural scientist, consists in the devising of methods which shall make all types of phenomena in their quantitative aspects completely representable in algebraic terms. Algebra itself exhausts the relation *and*. The other primary relations which phe-

nomena exhibit are those of *where* and *when*, the relations we call spatial and temporal. The abstract sciences of these relations — geometry, which is the science of configuration, and kinematics, which is the science of motion (there being no science of simple duration) — were developed independently of the science of number, though in natural coördination with it. The science of kinematics, which had its origin in that earliest astronomy which yielded us the concept of uniformly flowing time, was easily developed as an expansion of the science of geometry, since spaces and times are similar experiences — what we call continuous magnitudes, in contrast with the magnitudes that may be counted, numbers, which are separate or discontinuous. The problem which immediately presented itself, therefore, when it was first attempted to extend the methods of counting beyond the domain of number, was that of finding means for the complete representation of continuous magnitudes by discontinuous formulations.

The attempt was first made, while geometry was still in the earliest stages of its development, by Pythagoras and his disciples. Their motive, as it is transmitted to us by legend, was philosophical: a demonstration of their fundamental dogma, that all is number. Behind this dogma, however, we cannot but surmise — indeed we have direct evidence of — the working of a scientific instinct to unify the separate disciplines of arithmetic and geometry and thus to clarify the mathematical thought, which is to say, the whole scientific thought of their time. It is easy to appreciate the fact that this Pythagorean problem

is one of the most fundamental in the whole scientific range. Granted its solution, the sciences of number and configuration and movement — of *and* and *where* and *when* — would be methodologically, and thus philosophically, united; and it would need only the incorporation of a universally applicable expression for the spatial and temporal variability of force — a new scientific concept necessary to represent the compulsion of material movement, a *must*, let us say — to make all the grosser natural phenomena, which we call mechanical, susceptible to mathematical analysis in terms of number. The Greek successors of Pythagoras keenly appreciated this possibility. Within two centuries after his death, the Peripatetics actually attempted the kinetic definition of force; and though for lack of empirical knowledge they failed in this attempt, they stimulated the investigation which centuries later accomplished the desired result. Finally, even before their time, the Greek imagination had conceived a still more inclusive synthesis, based on the common knowledge that perceptible movement accompanies physical changes of every sort, which suggested the possibility of expressing every natural process whatever in the same terms, thus making their mathematics applicable to the whole range of physical phenomena. This was the Greek atomic theory, the prototype of our present atomistic scheme.

There is no more interesting and no more important chapter in the history of thought than that which traces the interlacing growth of these most fertile of all philosophical conceptions, upon which as everyone

knows the whole theoretical structure of modern science rests. It is sufficient for present purposes to be thus reminded that our entire conceptual scheme of nature has this simplest of all logical foundations. It is obvious that to this circumstance it owes its stability — its unvarying accord with continually multiplied observations of fact; for the ultimate terms of its most general and most intricate formulations still represent the most primitive forms of clear perception. The distance, time and mass (or energy) of the mechanist, which are the terms of his so-called dimensional or simplest formulations, to which all others are reducible, are only the exact representations of the *there* and *then* and *must* conceptions of the child; that is, all of his representations of general facts are expressible in terms of simplest conceivable facts — are built, so to speak, upon the bedrock of sense awareness, so that as knowledge grows, though they change in complexity they are persistent in essential form, or type. Mathematics has made them all measurable by counting, that is, representable in terms of the universal, invariable and still more definite primitive concept of discrimination, *and*. And finally, imagination, guided by instinctive inductive inference which experience has proven sound, has made them applicable to all phenomena by picturing these as mechanical processes in systems of different orders of magnitude.

This brief digression, which has involved considerations not strictly mathematical, will serve to emphasize the fundamental scientific importance of the Pythagorean problem: to express continuous magnitudes in terms of discontinuous formulations. It is obvious

that the solution of this problem was the one thing necessary to make the process of counting applicable to all physical science. The investigations which were stimulated by this realization are as interesting as they are important. It is impossible in a few paragraphs to describe them at sufficient length to make their suggestive interrelation and far-reaching influence in philosophy, mathematics, and natural science fully apparent; but a sketch of the most important phases of their development is the best possible means by which the conceptual substructure of scientific theory can be clearly presented. The results of these researches were permanent acquisitions: they provided the ideas which still remain fundamental in our present representation of nature.

To understand this history, it is necessary first of all that the nature of continuous magnitude be simply and clearly conceived. With reference to immediate intuition, this presents no difficulty whatever: the simplest experience of motion provides it. The path of any moving body is a continuous magnitude, and the duration of its flight is likewise continuous. These statements imply merely that, sensibly, such motion is steady, uninterrupted, not jerky but flowing. It is the motion itself which is thus first apperceived: its spatial and temporal elements are the results of an unconscious analysis and correlation of its various manifestations, and are both, therefore, likewise continuous. Of these, the spatial relations are the basis

of all measurement, since times are reckoned always by reference to spatial displacements. Geometry, therefore, the science of spatial relations, is the primary science of continuous magnitude, kinematics and chronology being developed scientifically by its application to the study of motion. The Pythagorean problem, therefore, in its generality, is practically solved when effective ways are devised for the complete description of geometrical magnitudes in terms of number.

All this is evident enough, and to ordinary people and natural scientists alike it would seem that the questions likely to be involved in this unification of mathematics were simple in the extreme. Such, however, is not the case; for geometry, like logic and the theory of number itself, as a consequence of its extensive conceptual development has become encumbered with various ideas, scientifically gratuitous, which complicate quite unnecessarily our customary study of its elements by making its basic conceptions mysterious and obscure. There are many who are not troubled by these ideas; but the greater number of us, probably, are still affected by them. It is worth while, therefore, before considering the Pythagorean problem itself, to clear the field of inquiry of irrelevancies by a brief consideration of the essential character of geometrical representations. This digression also may be not without interest in itself, since it will present another contrast between scientific and metaphysical habits of thought of a type already made familiar.

The earliest geometry was a natural science: the science of physical configurations. Herodotus traced

its origin to the practices of Egyptian surveying; but whether or not this conjecture be accepted as plausible, and generalized as a theory which would derive geometry from the practical mensuration of fields and buildings and grain-bins, and from the mapping of that celestial vault wherein the movements of the stars determined times and seasons, it is quite evident that its Greek development was stimulated in quite another way: by the art of designing, guided by an aesthetic appreciation of the beauty of symmetrical figures. The study of such figures, and the experimental construction of tile-patterns, decorative borders, conventional sculptures, moldings and the like, had made the early Greeks acquainted not only with a great variety of regular geometrical forms, but with techniques by which they could be constructed, compounded and divided exactly, in various ways.

Unlike their predecessors, the Greeks made an intellectual diversion of this occupation, as of all which they undertook. They observed that identical constructions could be made in different ways; perceived that these involved the utilization of invariable relations which obtained between lengths and angles and areas in similar figures; and were able to generalize these relations, at first intuitively, and later by deliberate method. They thus discovered by trial and inductive inference a number of interrelated properties of figures which clearly indicated the mutual dependence of all spatial relations; and, in the process of correlating these most simply and clearly, gradually eliminated from their thought about them all guess

work, all accidental experiences such as errors of actual drawing and measurement, and all ideas excepting those which were absolutely essential. Their science thus became a science of ideas exclusively, what we call an abstract science; and since the continued study of the phenomena showed clearly that every physico-geometrical relation approximately verifiable could be expressed in thought exactly as a demonstrable consequence of simple presuppositions, the number of which diminished as time went on, it gradually assumed the form of an elaborate deductive logic based upon a few intuitive assumptions. A rich and complicated knowledge was thus shown to be the mere development of a few very simple immediate experiences; and this demonstration placed in man's hands a scientific instrument of great power, invaluable for the further analysis of his experience.

The beauty and fascination of this scheme of immutable relations, even more than its utility, captured the Greek imagination. It seemed to reveal, or at least to promise to reveal, truths more profound than any which could be directly inferred from rough phenomena, truths fundamental and eternal: aspects of a final Truth. The intoxication of abstract thought which a newly awakened consciousness of intellectual power had already induced was thereby intensified. The magic of conception, which might it seemed be limitless, conferred upon abstract ideas of every sort, but especially upon those of geometry, a sort of mysterious potency which it was easy to ascribe to existence independent of the data of sense. They became in fact to the schools of philosophical thought which domi-

nated the first centuries of critical enlightenment, in particular to the Platonic school, the mirror of ultimate Reality. This inspiring supposition, by its imaginative grandeur compelling in itself, was sustained by the aristocratic pride of those who were glad to find good reason for their spontaneous scorn of vulgar thought and labor, as well as by the religious impulse which found in such transcendent ideas the basis of an absolute ethics and a consoling metaphysics. It bound together the intensest egotistic, intellectual, moral and religious aspirations. For this reason it persists today. It still determines the tone of much purely mathematical speculation, which assigns a mystical significance and a correspondingly superior dignity and value to purely conceptual thought, and which tirelessly strives to rid this thought of the last vestiges of its humble human origin. It inspires the equally mystical philosophy, developed later, which would now reduce all science to the logic of invariance. And more significantly still, it tinctures all common thought concerning abstract reasoning, and particularly all common thought concerning mathematics, with the glow of magical mystery. There are few who do not think of mathematics — admittedly more subtle and difficult than other scientific disciplines — as somehow, vaguely, more profound, more significant, and more ennobling also. Even scientific men accord it an exaggerated respect not wholly explicable as the tribute of unfamiliarity; and mathematicians themselves habitually encourage this deference, quite sincerely.

It is unnecessary to indulge this mood: and it is

scientifically advantageous to ignore completely the confusing thought it fabricates. There is no magic in mathematics if we do not believe in magic. That science is earth-bound like every other; for it cannot transcend its presuppositions, all of which are inductive inferences from experience. It has been made apparent already that the magical properties of numbers — those which are imagined when naïve attempts are made to assign real meaning to negative and complex numbers as such, for instance — are the figments of confused thought. All numerical relations may be derived from those of whole numbers; and these are generalizations derived from counting, and cannot be discussed excepting with direct reference to the ordered grouping of symbols handled as if they were objects. The presuppositions of geometry are even more clearly intuitive. They are best represented by the definitions, postulates and axioms of Euclid, from which all other purely geometrical propositions are derived. These definitions, postulates and axioms all refer to common experience.

Let us consider a brick; and in order to simplify our thought about it, let its surface be smooth and its opposite parts perceptibly alike. If we think about its shape and this alone, disregarding its color, weight, hardness and every other attribute but its shape, then by this act we make it a geometrical solid. The Greeks were well aware that geometrical solids had no other sort of existence. Space to them was that which held matter; Aristotle denied the existence of totally unbounded space, as inconceivable. It remains inconceivable in the sense that it is unrepresentable as actu-

ality. A geometrical solid is nothing more than the shape of an actual solid considered apart: that is, abstracted in thought. Similarly, if we consider the boundary of this solid and nothing else, we conceive a surface. This surface has no thickness because we are not thinking about thickness. In the same way the edges of the solid become lines, which have no breadth because they are the intersections of surfaces; and its corners become points which have no dimensions, but positions only, because they are the intersections of lines. These geometrical magnitudes thus exist, in thought only of course, as consequences of successive restrictions of our universe of discourse, and have no other existence. Their complete dependence upon the knowledge of experience is shown very clearly by their definitions. One illustration will suffice. Plato defined a straight line as whatever has its middle in front of both its ends; or, as one might say, it is that which viewed end-on is invisible: this defines the straight line as the path of a ray of light. Euclid defined a straight line as breadthless length which lies evenly with the points on itself: the idea of constant direction enters here, the meaning being that a straight line has the same shape with reference to all points upon it, appeal being made to a less simple (a more inclusive) intuition. To Heron of Alexandria, a straight line is breadthless length, which while its ends are fixed, itself remains unmoved when it is rotated. To Proclus, it is the shortest distance between two points — which leaves distance to be defined. All of these definitions are appeals to perceptual experience: it is otherwise impossible to define any geometrical magnitude.

These magnitudes, like all other scientific conceptions, are representations of actual experiences made simple and exact in thought for the purpose of clarifying thought. Their rôle in science is precisely that of logical propositions and algebraic formulations: they are patterns of reference; and the value of geometry is precisely similar to that of logic and algebra: it is a scheme of thought which exhibits invariable relations of configuration that would be revealed with difficulty or not at all by empirical measurement. The Greek mathematicians probably realized as clearly as we do that, merely as an instrument of investigation in natural science, a wholly empirical geometry would suffice. Excepting for their great convenience in abbreviating the procedures of research, the absolutely exact relations of geometry are no more necessary in investigation than are those of formal logic. Inasmuch as the generalizations of natural science are all affected by errors of observation, it is clear that precise mensuration would serve all the scientific purposes of exact geometry, just as other experimental procedures might function as a substitute for logical deduction. The disadvantages of such empiricism are obvious enough. The inestimable value of deductive logic has already been discussed: all of this value likewise appertains to geometry. It is interesting, however, thus to remark in passing that science is not completely dependent on either, however more difficult our problems might become were we deprived of their aid.

The Euclidean postulates still more clearly exhibit the dependence of geometry upon experience. The first three of these — which assert the possibility

of drawing a straight line from any point to any other point, of producing a straight line continuously in a straight line, and of drawing a circle with any center and radius — refer directly to the idealization of simple acts, and imply that the straight line between two points is unique, that two straight lines cannot enclose space nor have a common segment, and that space is continuous and unlimited. These are statements verifiable only approximately by physical experience. The fourth postulate, by asserting that all right angles are equal (wherever they are placed), affirms the invariability of figures, or the homogeneity of space: a presupposition of common thought which is quite unprovable, and which marks a limitation of ordinary experience which Euclidean geometry shares. The famous fifth postulate, which involves the fourth, confesses that it is impossible to prove (otherwise than roughly by trial) that only one line may be drawn parallel to another through a point, or independently of this assumption, that similar figures of different size exist, that all the angles of a triangle are together equal to two right angles, and so on. Nothing but a general consistency between the abstract geometry derived from these postulates with the results of actual mensuration vouches for their general truth. In recent years geometrical schemes of thought have been devised which are based upon other postulates. These are equally self-consistent; and it now appears to be not unlikely that, in order to make our geometry completely accord with certain results of recent physical measurement, one of these, which involves a denial of the fourth and fifth postulates of Euclid, will have

to be adopted in future scientific work. The Euclidean geometry, which is still wholly consistent with all ordinary experience, would then be looked upon as a workable approximation, not quite generally true, but true within definable limits of precision in measurement. Finally, the axioms of geometry, which are generalizations of very simple experiences not exclusively geometrical (such as that things equal to the same thing are equal to one another, or that if equals be added to equals the wholes are equal) must also be admitted as essential presuppositions in its reasoning. These, like the postulates, are true only because they accord with the results of measurement.

All these further observations serve to emphasize the priority of experience in every phase of scientific work. Like the intricate constructs of logic and algebra, those of geometry constitute an idealized scheme of representation and nothing more. Even when, for the sake of eliminating its embarrassing definitions, geometry is cast into logical form, then, whatever may be thus accomplished in the way of making it less heterogeneous, its dependence upon experience is unaffected, for postulates remain. In short, to reduce the whole matter to the perfectly obvious, in all reasoning whatever we must build on postulates of some sort; and with respect to logic and mathematics as a whole these postulates are many. They are, invariably, elements of experience in the world of events, called intuitive whenever the processes of inference which have yielded them have been unconscious or unremarked. This matter decided, it is now possible to consider the Pythagorean problem out

of its mystical setting and thus without confusion, simply as a problem of consistent representation of phenomena in thought.

The early Pythagoreans, in their first attempts to correlate geometry with arithmetic (by which they meant not the art of calculation but the theory of number), simply represented various rectilinear geometrical configurations by systems of dots symmetrically disposed. By the study of these patterns, as the figures represented by them were expanded and combined, they were led to the classification of numbers by geometrical forms — whence originated, for instance, our surviving classes of square and cubic numbers — and to the study of progressions and of ratios and proportions. These first researches at once suggested the idea that all configurations might be similarly represented, and thus, in the Pythagorean view, be looked upon as actually composed of points, or monads, which could be counted; that is, it seemed that the science of continuous magnitude could be reduced very simply to that of number. But it was not long before the Pythagoreans themselves discovered that the ratio of the diagonal of a square to its side could not be represented by any ratio whatever of natural, whole numbers — in other words, that there existed between continuous magnitudes relations not representable in their arithmetic. This embarrassing discovery upset their original theory completely; but they faced it with honorable candor, actually demonstrated it logically

with admirable ingenuity, and later amplified the destructive evidence it provided by identifying similarly many other incommensurables which they studied and classified.

This new knowledge, so far from leading them to abandon their theory, stimulated renewed efforts to develop it. There was only one way in which this could be done, and this way they forthwith chose. Their elementary monads were made infinitesimal: a geometrical line, for instance, was henceforth looked upon as an infinite number of vanishingly small points. Correspondingly, a circle might be considered as actually a polygon, with an infinite number of infinitesimal sides; a cone as consisting of coaxial cylinders of infinitesimal heights, the diameters of which decreased from base to apex by infinitesimal gradations. Such conceptions were difficult, of course, to any but rough and ready thinkers. If, for instance, a line were supposed to be actually composed of points, then these points would have to be something different from those which were formed by the intersection of lines; for these would have no dimensions, and to make them actually compose lines would mean to create a dimension out of nothing, and would imply the possibility of similarly creating space — even if one confined his magic to the geometrical realm. And to make the method applicable to physical science, it would of course actually become necessary to allow this miracle to operate with masses, forces, and life itself. On the other hand, if one hesitated to play god in this manner, the line monad would have to be a line indivisible in thought; but this would be a denial of

actual continuity, and since even the series of natural or fractional numbers is infinite, it would make every line segment of infinite length and leave the character of its discontinuity indeterminate.

Pragmatically, of course, this way of looking at things might prove to be very useful. One might, for instance, choose for use in certain problems monads of merely negligible size as units, and if at any time, with increasing precision of measurement or increasing exactitude of thought, they became large enough relatively to other dimensions considered to obtrude themselves upon one's notice to his embarrassment, he might make them smaller; and could proceed in this manner as far as he wished. Fluctuating monads of this character were actually employed to good effect by Democritus, who proved by their means that the volume of a cone is equal to all intents and purposes to one third that of its circumscribed cylinder. They were also used by Archimedes, who calculated the ratio of a circular circumference to its diameter very closely indeed, and in an investigation which he considered preliminary, effected the quadrature of a parabolic segment quite similarly. The practically minded mathematicians of the seventeenth century who developed the calculus conceived infinitesimals in like manner, utilized them systematically, and, after Newton and Leibnitz, employed perfectly general methods precisely formulated, all of which involved the idea of quantities indefinitely but negligibly small, for the solution of the most complicated and difficult mathematical problems. In short, this essentially practical handling of a rather fuzzy idea yielded science at

length its most powerful instrument of conceptual analysis.

The Greek mathematicians, however, were not satisfied to be pragmatists of this sort. They certainly realized as clearly as we do the usefulness of the fluctuating monad; but they were not content to use inconsistent conceptions in geometry, which when logically developed would never yield more than plausible suggestions, the validity of which could be established only approximately by actual mensuration. They were designing a scheme of representation the whole of which should be demonstrably true if its few postulates were granted; susceptible therefore to logical elaboration in detail similarly valid and dependable: a self-consistent science of space, in short, the most involved conclusions of which should be as unquestionable as its simplest assumptions. From a wholly practical point of view, their refusal to compromise their thought with vague or inconsistent ideas was obviously quite justifiable: for the efficacy of their scheme of thought as a scientific instrument would certainly have been seriously impaired excepting for this caution. It is impossible now to discover how far this sufficient motive carried them: it was, without the slightest doubt, powerfully reinforced by the expectation or belief that geometrical knowledge was more significant than that of ordinary experience. At all events, the rigor of their thought, despite their lively imaginative impulse, was sustained until their science was completed. The Greek geometry, like the Aristotelian logic which it inspired, remains today one of the most perfect of all the products of human genius.

On account of its vagueness, and because of its inconsistency with other geometrical conceptions, then, the Pythagorean theory of monads was rejected by the Greeks. It received its *coup de grâce* at the hands of the Eleatic philosopher Zeno, who, having demonstrated its inconsistency in geometry, showed further that continuity could not be thus atomized in thought without, by implication, denying the evidence of the senses. His famous paradoxes showed, for instance, that if a line were actually composed of infinitesimals, then Achilles would never overtake the tortoise — and so on. Whatever the philosophical motive of Zeno's criticism may have been, his successors interpreted it scientifically, as demonstrating that, since the Pythagorean theory was inconsistent with experience, it must be rejected.

This common-sense judgment had far-reaching consequences. In mathematics it led in the first place to two remarkable achievements, both due to the genius of the great geometer Eudoxus: the establishment of a general theory of ratio and proportion, by which the relations of incommensurable magnitudes could be rigorously defined despite the impossibility of numerical representation; and the development of the method of exhaustion, which effected the unification of geometry by providing means for the logical demonstration of quantitative relations between rectilinear and curvilinear figures without recourse to the conception of the monad. The importance of these achievements, and particularly that of the analogous conceptions which they involved (which made possible the rigorous definition of undeterminable quantities

in terms of greater and less alone) will be fully appreciated if we recall that the one provides the foundation of our present scientific conception of number, and that the other establishes the logical validity of the infinitesimal calculus. They are the outstanding consequences of a veritable revolution in scientific habits of thought; for after Zeno, the conceptions — if such they may be called — of the completed infinite and the actual infinitesimal were excluded from Greek science. According to Aristotle, who expresses the matured opinion of the ancients most succinctly, the infinite has existence as potentiality but not as actuality; as something, that is to say, toward which experience may reach out, but which it may never grasp. In modern times, the old Pythagorean ideas have been more than once revived, and have been used in scientific exploration, as has been stated, effectively: they also still confuse much philosophical speculation, for their mystical appeal remains to many quite irresistible. In purely scientific theory, however, they find no place. Our present interpretation of the infinitesimal, for instance, is defined by a theory of limits which merely re-expresses the rigorous conception of the Greek mathematicians in more congenial form.

After Eudoxus, the quantitative relations between continuous magnitudes were gradually developed by geometrical demonstrations which established equalities between line-ratios variously compounded and divided, between rectangular areas both square and oblong likewise compounded and divided, and between these and rectilinear areas of all sorts. These relations were made perfectly general by application

of the new theory of proportion: that is, they were shown to hold for incommensurable as well as for commensurable magnitudes. The method of exhaustion permitted this extension to include the relations of rectilinear and circular areas, of pyramidal and polyhedral as well as parallelopipedal volumes, and of cylindrical, conical, spherical, conoidical and toric areas and volumes, as the field of geometry rapidly enlarged; and after Archimedes had closely estimated the ratio of the circumference of a circle to its diameter, these relations yielded at once to those whose interests in the Greek view were practical rather than scientific, the principal formulas of mensuration — our familiar $2\pi R$, $\frac{4}{3}\pi R^3$, and so on.

Purely geometrical representations of quantitative relations, because of their exact generality — specifically because they made the incommensurable ratios seem very real by actual drawing and perfect visualization — were preferred by the Greeks to any form of necessarily imperfect numerical representation. It was only toward the end of their scientific career and under the influence of practical interests and habits of thought Egyptian rather than Hellenic, that they began to abandon these logically irreproachable but cumbersome representations for more facile algebraic formulations. Meanwhile, however, they had thus expressed the fundamental laws of what we call algebraic transformations; had worked out demonstrations equivalent to the solution of the general quadratic equation for real values of the unknown quantity; and, through the study of continued proportions, had solved in similar ways certain types of cubic equations.

The foundations of algebra were laid in this manner. Its much later development from the numerical point of view was very slow. The simplest equations yielded not only incommensurable quantities which could not be exactly represented by any numerical notation, but negative and then imaginary quantities which had in themselves no meaning. The interpretation of these results had to await an extended study of their relations in the equations themselves, by which alone their significance could be grasped and their arithmetical transformations consistently effected. Meanwhile, naturally enough, the algebraic processes which led the mathematician into these mazes of mystification were employed by the careful with somewhat apprehensive caution, especially since they offered the most inviting opportunities for phantasies of thought. The fascinating problems of conception which they presented compelled persistent research, and as facile devices of calculation they held their ground, for real — or understandable — results could always be verified. Until the middle of the sixteenth century, however, the algebraic solutions of equations were always guided and controlled by geometrical representations which, by visualizing their processes, gave meaning to their obvious results and suggested possible meanings for their obscure results, with reference to the intuitions derived from experience with spatial relations. When in the middle of the sixteenth century Cardan effected the solution of the general cubic equation, he employed devices derived from geometrical intuitions. His work, however, involved in its development the multiplication of cubes; and his subsequent reapplication

of the relations already discovered to cubes treated as units made them purely formal. In other words, when equations of higher degree than the cubic were investigated, the assistance of geometrical intuition in algebra was no longer possible excepting in so far as it could suggest forms of conception analogous but not identical: mathematical forms in the modern sense, quite general, and expressible only in algebraic terms.

From this time onward, therefore, it became necessary to develop the science of algebra independently of geometry. There still remained not a little confusion of thought concerning the meanings of negative and imaginary numbers, which now had to be defined by their algebraic relations alone. Arbitrary geometrical pictures of these relations were invented, and employed as patterns to clarify conception by continued appeal to intuition; but these patterns henceforth represented relations only, and as acquaintance with purely algebraic forms became more intimate, and with the development of a generally applicable and consistent symbolism more sharply definite, their geometrical analogues became less useful. As the algebraic forms became more complicated, also, such appeals to intuition began to be confusing, even when they were possible. The system of numerical relations, generalized by algebra, despite the impossibility of representing many of its terms as such in thought, became, in short, more easily understandable than any intuitive imagery whatever. It was realized, at length, that the numerical scheme of representation was not only vastly more inclusive than the geometrical, but that — when it was conceived as a system of relations,

and its isolated terms defined accordingly — it was incomparably clearer. To make a long story short, the experience of mathematicians, after years of experimentation with ideas, had led to the conviction that of all forms of conception, that of number alone is completely definite and unambiguous. In physical science we have learned that if thought is to be productive, its primary concern must be the study of quantitative relations: in mathematics we have learned that this study, if it is to be effectively pursued, must be based not upon the quantitative relations of continuous magnitudes, but upon those of number.

After centuries, therefore, the insight of old Pythagoras is completely confirmed. Certain logicians still dispute the testimony of experience and write long treatises to define the number 1; and these men and others still confuse our thought about the counting which begins with 1 and ends nowhere, by mystical imaginings concerning its significance as Idea. But scientifically, these indulgences of metaphysical yearning are unproductive: they offer us nothing but an explanation of the utterly simple in terms of the unimaginably complicated and vague, and they are becoming a veritable nuisance, not only to the simple-minded natural scientist, but to the subtle mathematician himself. Our theory of nature — the scheme of thought by which we try to make it understandable — must be based upon some unanalyzed conceptions which we take for granted; and if it is to be understandable, its fundamental conceptions must be clear and unequivocal. For this reason we choose, to begin with, quantitative relations; and we express these

numerically, without asking further what number really means — for the question itself has no scientific meaning.

Mathematics, then, has become, so far as possible, exclusively the science of counting: the science of number and order. So far, so good; but this clarification leaves the Pythagorean problem still unsolved. Phenomena present themselves in space and time, and are simply and clearly describable only with reference to the primary continuity of motion which all involve, and of which the measurable aspect is idealized in the space continuum of geometry. To describe phenomena mathematically, therefore, the number system must be developed, without losing its unequivocal definiteness, to such an extent that every observable geometrical relation may be completely described in its terms. This development has at length been satisfactorily effected; and its theory, which establishes its simple definiteness and complete adequacy in this respect, is called the theory of mathematical continuity. This continuity is something very different from the geometrical continuity which idealizes physical experience, and must not be confounded with it. The old Greek problem of finding multiplicity *in* unity, the problem which Phythagoras attempted to solve by his original theory of number, has been given up. We no longer think of a line as being made up of points, or of any physical or geometrical magnitude as actually consisting of numbers. The criticisms of Zeno have never been answered; and such conceptions, therefore, are rejected by us, as they were by Aristotle. We strive no longer to discover elements

of identity between numerical and geometrical magnitudes, but are content to establish a parallelism or complete correspondence between them as distinct and irreducible aspects of experience; and the theory of mathematical continuity, by verifying this correspondence, permits us to look upon them as different conceptual representations of the same phenomena. The original metaphysical problem has thus become scientific: a problem not of the nature of reality, but of consistent representation; that is to say, though many mathematicians would dislike to admit it, a pragmatic problem.

Our customary procedures in the algebraic representation of geometrical configurations — the procedures of analytical geometry, originally devised by Descartes early in the seventeeth century — illustrate this very clearly. If any curve may be constructed geometrically, this obviously implies that certain invariable relations obtain between the magnitudes which together determine it. Thus, an ellipse is a curve each point on which is determined by the requirement that the sum of its distances from two fixed points shall be constant: the curve may therefore be roughly drawn by placing an inelastic loop of string loosely around two pins, straightening it with a pencil to form a triangle and moving the pencil while maintaining the tension. All geometrical curves may be looked upon as loci similarly generated, but in thought. Their characteristic continuity is thereby vividly visualized by the primary intuition of motion, and their points are then clearly imagined as instantaneous positions of the generating point. If the curve

represents an actual motion, then the requirement which determines these successive positions represents a mechanical law, or, as one would usually prefer to express himself, some aspect or consequence of such a law. These requirements may always be expressed algebraically. For the sake of uniformity and simplicity they are customarily represented by equations which define the position of any point on a curve by the algebraic relations of its distances — expressed, let us say, as x and y — from fixed axes of reference usually at right angles to each other. These equations of the curve may be developed algebraically at will with the greatest ease, and may thus be employed to reveal any geometrical property of the curve with reference to chords, tangents, intersections with other curves, and so on. Relations of high complexity may thus be investigated with very little mental strain which would be extremely difficult by pure geometry. The corresponding algebraic treatment of trigonometrical relations, and the generalization of the algebraic methods of infinitesimal analysis, which correspond to the old Greek methods of exhaustion, develop these advantages still further: to such a point, indeed, that pure geometry — excepting its elements, which still provide the most effective methods for the study of very simple problems easily visualized — has almost disappeared from mathematical writing. The *Conics* of Apollonius, which systematically developed the properties of conic sections by pure geometry, and which remained the standard treatise on the subject as late as the beginning of the eighteenth century, is now very difficult reading even for

the skilled mathematician; and not many physicists are able to study with unembarrassed appreciation even the modern *Principia* of Newton, a work which the inventor of the calculus composed in purely geometrical form, not only that his contemporaries might find no justification for logical criticism of its method, but also that they might more easily understand it.

The Pythagorean problem has thus been solved. Our number system, which may be completely derived theoretically from the system of whole numbers, is sufficiently rich to represent arithmetically or algebraically any relation of spatially continuous magnitudes which is representable geometrically. The two types of representation have not been reduced to one, but they have been shown to be in exact correspondence. From what has been already said, it is clear that even if in the old philosophical sense we may not imagine that space is made up of points, we may treat it, and do treat it as if it were. This means that within the field of pure mathematics, which is that of conception only, space really is a totality of points: for in conception, obviously, that which is thought, is. In other words, to the mathematician as mathematician there is no Pythagorean problem. In simple operations, he may, if he chooses, think of space as a geometrical continuum, and by this act he makes it such. Or in the next instant, for the sake of reasoning more easily and clearly, he may think of it as an infinite multiplicity of points, and lo! that is what it is. The Real World of conception has this character: you may make it anything you choose. It is kaleidoscopic; indeed, it is miraculous, for not only may it undergo

instantaneous metamorphosis in this manner; it may possess two or more kinds of existence at one and the same time. In ordinary conception — the kind we call imaginative or poetical — these may even be contradictory: for this closest approach to absolutely pure thought is linked to fact only by its elementary images. Mathematics, however, like logic, is bound to fact by its ideas of relation as well, and this makes it consistent with itself and, incidentally, useful. It still possesses, however, several degrees of freedom, as already remarked; for it takes no account of the world of events.

Whenever this distinguishing characteristic of pure mathematics is disregarded (that it takes no account of the world of events) confusion of ideas is the inevitable consequence. The modern mathematical habit of thought recreates the ancient Pythagorean representations, and the persistence of these in the mathematical mind conveys to many the insistent suggestion that they have physical meaning. It is, consequently, important always to bear in mind the fact that such is not the case. If lines and spaces were nothing else than infinite totalities of points, there would, as Zeno proved, be no such thing as motion. But motion is an element of primary experience. The spatial and temporal intuitions which we derive from this experience, therefore, and the geometrical continuum which idealizes them, constitute the only scientific representation of space which is consistent with the whole of our experience. The mathematical continuum of numbers and all the mathematics of its elaboration is a methodical device, a framework of ideas derived from the

simplest of all our experiences of universal relation by repeated abstraction: from the scientific point of view an instrument of research, from the mathematical point of view a scheme of thought sufficiently interesting in itself, but from no point of view a representation of things as they are.

As a consequence of these long-continued mathematical investigations, the science of motion as such, or kinematics, was given secure foundation and was provided with methods by which it could be developed mathematically in terms of number; for the time factor in motion had long been determinable physically by reference to the equi-angular division of the circle which corresponded to the period between meridional transits of particular stars, the apparent speeds of which were assumed to be constant. To make this knowledge applicable to mechanical phenomena it was necessary, in the next place, to discover a kinematic expression for the spatial and temporal variability of force — in other words, a description, so far as possible in terms of motion, of the compulsive factor in actual movements, which should be completely consistent with experience. The difficulties which had been encountered thus far were difficulties of conception wholly, for the primary intuitions of number, space, and time as spatially apprehended through motion, were perfectly clear. The experience of compulsion, on the other hand, though vivid enough, was too general to be distinct. The difficulty of giving it a quantitative definition, therefore, was one

of a wholly different sort, for it necessitated not an analysis of ideas alone but of experience in the world of action; and since, furthermore, experiences of compulsion were not only various, but were also variously superimposed, it demanded experimental investigation.

There is no doubt that this problem of defining force was one of the most puzzling in the whole range of past scientific research. The mathematical habit of thought which Greek science had thoroughly inculcated had practically exhausted itself in the field of mechanics when Archimedes, reasoning deductively from a few new intuitive postulates, inferred the law of the lever and its variants, the general theorem of the center of gravity, and the laws of hydrostatics together with the principle that goes by his name. The ancients thus established the fundamental laws of balanced forces or static equilibria — briefly, the science of statics — and there is little doubt that had their science continued to develop in its characteristic manner there would have been nothing left for the moderns to do in working out its fundamental principles; for Stevin, Galileo and their successors, working in this field, reasoned in a precisely similar manner. As it is, though these moderns enriched the ancient knowledge of balanced forces by envisaging the phenomena from various points of view, they added nothing (prior to the discovery of atmospheric pressure) that was not implicit in the Greek mechanics, and quite within the grasp of the old geometers.

None of this mechanics, obviously, involved the study of free motion. Alone among the ancients,

Aristotle, or the later Peripatetic whose work is ascribed to him, appears to have attacked the general problem of dynamics: that of the kinetic formulation of force. The vision of the philosopher is here apparent: unfortunately his work was carried out before the times were ripe for it; for in his day, perhaps a century before Archimedes, the Greeks were not experimentalists. The Peripatetic conceptions, consequently, were derived from commonplace experiences, plausibly enough, but in error. It is necessary here only to indicate the character of ancient reasoning with respect to the general conception under consideration. In the Aristotelian world, every elementary form of matter had its proper place: earth nearest the center, water above it or surrounding it, air above the water — lithosphere, hydrosphere and atmosphere from center outward; and the tendency of every body set in violent motion was to return to its proper place. If it were free to move, it fell or rose to its proper place vertically, and came to rest there. Generally speaking, a body at rest tended to remain at rest, and a body in motion tended to come to rest, in its proper place. The final condition of the terrestrial world, the state toward which all mechanical changes tended, was thus conceived as one of complete immobility. Motion and force were, therefore, concomitant phenomena: different aspects of a single action. The efficacy or compulsion of a moving body, consequently, was to be measured by its quantity of motion: its weight — or as we should now say, its mass — times its velocity. In other words, a constant force was that which is measured by unchanging velocity in a given

mass. It followed immediately that the efficacy or compulsion of a completed action would depend either upon how long it persisted or through what distance a body moved — either one, since the motion considered was uniform.

This conception of force, based upon a perfectly reasonable commonplace conception of the general nature of things in the terrestrial world, was accommodated with difficulty to the actual phenomena. Bodies fell, for instance, with different velocities, and the longer or the further they fell, the more rapidly they moved. The clue to their differences in velocity under the same circumstances was afforded by observing that they were variously affected by the resistance of the medium: denser bodies fell more quickly. The acceleration of their fall was more difficult to account for; it was also ascribed to the influence of the medium, but never satisfactorily. Attempts at the quantitative determination of these effects were apparently never made by the ancients, and their guesses were contrary to fact. Despite its plausibility, the Peripatetic theory thus remained undeveloped by the later Greek mechanists, who from force of habit confined themselves thereafter to the deductive study of simpler intuitional postulates, after the manner of Archimedes. It was not reconsidered until the seventeenth century.

The new enthusiasm for experimentation which animated the natural philosophers of the later Renaissance, as everybody knows, opened a new era of scientific investigation. One of the earliest, and certainly the most important of all the achievements of the

physicists of this period was the solution of the Peripatetic mechanical problem. This was effected by the classical experiments of Galileo on falling bodies. The great Florentine experimentalist was thoroughly familiar with Aristotelian doctrine, and well appreciated both its value and its defects. Fully conscious of the fundamental importance of the principles he sought to discover, he conducted his crucial investigation with great care, checking his inferences at every stage by ingenious and convincing tests. This investigation remains, therefore, a model of experimental procedure; and, on account of its simplicity, a most instructive illustration of scientific method. For this reason it may quite properly be here described in outline.

Galileo, in the first place, had inferred from a large number of mechanical experiments that the influence of a medium as tenuous as air upon the movements of heavy bodies was very slight; and this inference, taken in conjunction with the complete failure of Aristotelian theory to account for the maintenance or quickening of the speed of bodies in motion by ascribing it to the effects of currents of displaced air, led him to look upon the accelerated motion of falling bodies as characteristic rather than accidental. He assumed, therefore, that under the compulsion of the force of gravity, the uniform effects of which showed it to be constant, and independently of the influence of the medium, the longer and the further a body fell, the more rapidly it fell. His immediate problem, then, was to discover a quantitative relation between the final velocity of a falling body and the time and distance of

its fall. In the absence of any knowledge which could suggest the character of these dependencies, he was obliged to devise a procedure of hypothesis and verification. At the outset, then, he considered the simplest possible relations of dependence: first, that the final velocity was proportional to the space traversed; second, that it was proportional to the time of fall. He rejected the first of these hypotheses because he thought, in error, that it involved absurdity: he then worked out the consequences of the second, deductively. This logical development revealed the fact that if final velocity was proportional to the time of fall, the space traversed would be proportional to the square of this time, and conversely.

This relation, unlike that of the original hypothesis itself, was one which he saw a way to test experimentally. Thanks to the results of Galileo's work, we may now measure an instantaneous velocity; but he could not. On the other hand, the measurement of the spaces traversed by a freely falling body during given times, or of the times of its fall over given heights, seemed not impossible. The velocities attained by freely falling bodies, were, however, too great to be measured with precision in Galileo's day. He possessed no mechanism similar to a stop-watch: accurate clocks, indeed, were not known for some time afterward. In his experimentation, therefore, Galileo substituted for the freely falling body a ball which rolled down a smooth inclined plane. He justified this substitution by observing that a vertical plane, which would be parallel to the direction of free descent, was in fact an inclined plane in one of its limiting posi-

tions, and that no geometrical or physical evidence indicated that in comparison with other inclined planes it possessed any singular properties. Excepting for the variability of solid friction on inclined planes — which could be reduced by proper precautions to probably negligible magnitude — the motion on such planes, therefore, would be wholly similar to that of free descent; and in case it were sensibly of the same character for planes of different inclination, it would be proved to be so, within the limits of error in measurement.

With balls rolling down planes of several inclinations, then, Galileo made his primary observations. His method was to determine the times which elapsed while a ball traversed marked distances on the plane. He managed to measure these times with considerable precision by using a modified form of the old Greek water-clock: a vessel holding water, of large diameter and small aperture, which delivered at a rate sensibly constant for short intervals of time. The aperture he opened and closed with his finger, and the water delivered during the descent of the ball over his marked spaces he caught in a small vessel and weighed. By the repetition of identical measurements carried out in this manner he determined his experimental error to be about the tenth of a pulse beat, or less than the tenth of a second. His error of method, made variable by the use of planes of different length and slope, was shown by the data to be no greater than this, thus proving that the precision of his determinations probably represented their true accuracy; and this precision he thereupon improved by a multiplication of measure-

ments which reduced their accidental variability. In all, he carried out over a hundred determinations.

In this manner Galileo proved that in descent over an inclined plane and therefore in free fall, the space traversed was, in fact, within his experimental error, proportional to the square of the elapsed time; and the final or instantaneous velocity, therefore, proportional to the time itself. Having already made himself familiar with the statics of the inclined plane, he then deduced from this fundamental law several further consequences, the most important of which were that the actual acceleration of free fall was to that of descent on the plane as the length of the plane was to its height; that the final velocities of bodies which descended planes of the same height but different inclination were the same, and equal to that of free fall through their height; and that consequently, if a ball rolled down one plane and then (without loss of impetus by irregular motion) rolled up another of any inclination, it would rise to the same height as that from which it had fallen. This third inference he verified by ingenious experiments with the pendulum, of which the bob was pictured as moving on imaginary curved surfaces which were represented in thought as composed of inclined planes of infinitesimal lengths.

One of the consequences of this inference was exceptionally illuminating. Suppose a ball to roll down an inclined plane, and then to rise on one of less inclination: it will rise to its initial height, and will therefore ascend through a longer distance and consequently for a longer time: this time will increase as the inclination of the plane of ascent is decreased; and

if this inclination is finally made zero — in other words, if the plane is made horizontal — the ball, excepting for the effect of friction, would roll on forever. This conclusion marks the establishment of that fundamental law of motion, which, after it was formally enunciated, became known as Newton's first law. It will be remembered that from commonplace experiences Aristotle had inferred that in the nature of things, in the terrestrial world, a body at rest remains at rest, and a body in motion comes to rest. Galileo, on the contrary, discovered, and Newton explicitly stated, that although it is true that a body at rest remains at rest, a body in motion does not tend of itself to come to rest, but continues to move with uniform velocity in a straight line, unless it is compelled by force to stop or to move otherwise.

This observation made vividly evident a logical implication of the original discovery: namely, that the force associated with free motion is not proportional to the uniform or average velocity of the moving body, as Aristotle supposed, but to its change of velocity in time, that is, to its acceleration. Force, then, had to be formulated kinematically so far as possible in terms of acceleration. Obviously, however, it could not be measured by acceleration alone, for when bodies move with the same acceleration, the mechanical effects of their impacts, speaking roughly, are greater for larger bodies than for small ones. To complete the kinematic formulation of force, therefore — to make it, as we say, kinetic — it was necessary to define this second variability.

An earlier experiment of Galileo provided the evi-

dence which permitted this. At Pisa, in his youth, he had shown, to the astonishment of his Aristotelian colleagues, many of whom refused to believe the evidence of their senses, that dense bodies of very different bulk and weight fell with the same average velocity. The force, conceived as separately existent and propelling them, was thus shown to be proportional to their several resistances against being set in motion, or, with reference to the new knowledge, against changing their uniform rectilinear motion. This common property, which we now call inertia, was then loosely thought of as weight. When, however, weight was more sharply identified as the actual force of gravity, the term thus used became ambiguous; and when it was discovered that the weight of a body was different at different latitudes and was always proportional to acceleration, it became misleading. Many years elapsed before the constant proportionality between weight (or force) and acceleration was accepted as a fact which could not be more clearly defined. Newton, using one of Galileo's older alternative designations, called the magnitude which defined this proportionality mass, and conceived it as quantity of matter. He could not, however, thus independently define it. With different quantities of the same substance it was clearly proportional to bulk; but for different substances it was proportional to bulk times density, and density could be defined only as the ratio of mass to volume. Moreover, the general conception of matter could be made scientifically explicit only by the designation of the one property common to all matter, which differentiated it from mere space; and

this was mass. The situation of the early modern physicists who thus attempted a materialistic definition of mass was similar to that in which the old Greek geometricians found themselves, who attempted to define a straight line. Mass, indeed, *was* a universal property of matter; but it could be defined only as the proportionality factor between force and acceleration. In proof of this it could be measured only by the comparison of forces (ultimately of weights when accelerations were sensibly identical). In the way of further designation, therefore, the best that could be done was to make the conception vivid by illustration. Such illustration had the same value in dynamics that it had in geometry: by appeal to various sorts of common experiences it made the new conception familiar. Today we customarily demonstrate the property of mass by exhibiting the resistance to motion or change of motion of bodies not acted on by forces in the direction of the action: such as the resistance offered to sensibly horizontal displacement by a heavy motionless weight suspended from a long wire, or the resistance of a still flywheel to rotation, or the resistance of a cannon ball rolling horizontally on smooth ice to being brought to rest.

The discovery of the constant proportionality between force and acceleration, more intimately apprehended as the material property of mass, solved at length the problem of defining force kinetically. It was long, however, before the subtle ideas involved in the development of this definition were fully clarified. For instance: a force is defined as mass times acceleration; but what defines the efficacy of a force, the full

mechanical effect of a given action, its compulsion, in short, which is in the end what we are after? A long dispute raged over this question, which was settled at length by the realization that it was ambiguous, and that both parties to the controversy were developing valuable conceptions in terms of which the question itself could be given clearer definition. In this manner, mechanical conceptions originally crude were gradually made sharp and unambiguous; familiar phenomena were quantitatively described in terms successively more simple, and their puzzling interrelations clarified by the comparison and generalization of new precise formulations. In short, the science of mechanics, in the century of Galileo, Huygens and Newton, passed through a phase of development very similar to that which Greek geometry passed through in the centuries of Pythagoras, Eudoxus and Euclid. Then, its premises having been amplified and fully generalized by Newton, it rapidly developed into a consistently organized scheme of representation — formal and over-accurate, but in every aspect consistent with mechanical experience within the range of the possible conceptualization of such experience — by reference to which the most complicated phenomena could be unravelled and analyzed and typified, and their interrelations unequivocally and precisely defined. Its inductive postulates or principles — those of the mechanical uniformity of nature, and the invariability of cause and effect, of mechanical continuity, of independent actions or causes, and of conservation — were repeatedly confirmed by multiplied experiences, and were thus ultimately established as

basic natural laws. Its propositions, all derivable from the experimentally determined conception of force, were likewise conclusively verified; and their application to the analysis of newly-discovered phenomena was so successful that within another century the science embraced not only a complete explanation of all terrestial motion perceived as such, but of celestial movements as well, which the later Greek astronomers had never even thought of as mechanical. And the whole of this vast range of complicated phenomena was described by the new science in terms of the simplest of all possible conceptions: of distance and direction, time, and mass, the scientific analogues of the primitive ideas of extension and duration and compulsion — of *where* and *when* and *must* — brought into quantitative correlation and made precisely intelligible in any aspect at will by a mathematics which merely elaborated the equally primitive conception of conjunctive relation, *and*.

To summarize such magnificent achievements in this cursory way is both unsatisfactory and unagreeable, but it cannot be helped. Our present purpose is served when the general manner of development of our scientific scheme of thought is realized. All questions as to the actual content of this thought, all description of the epoch-making discoveries which the new theoretical conceptions made possible, all discussion of their general intellectual and social influence — this is the business, not of the discursive critic, but of the historian of science. He has, for instance, told us how the new mechanics revolutionized our conception of the world. He reminds us that to the moderns

before Galileo as well as to the Greeks, there was no connection between astronomical and physical phenomena; that to Copernicus, as to Aristotle, the eternal celestial motions were circular and therefore unanalyzable, perfect, and divine, the centers of their compounded revolutions being points in empty space. And he has explained how Huygens was able, with the new idea of force, to disprove this assumption by analyzing circular revolutions into uniform rectilinear motion and centripetal acceleration; how, since already Kepler's measurements had shown that the planets moved, not in perfect circles but in elliptical paths about material bodies, maintaining mean distances from the sun in fixed relation to their periods of revolution, it was then possible for Newton, by generalizing Huygens's results, to show that the planetary movements also involved centripetal acceleration, which varied inversely with the square of the distance; how he guessed that the corresponding interplanetary force was identical with that of gravity, and proved it to be so for the moon; and how, after a century of labor, his successors unified the mechanics of the whole universe of measurable motion, by finally establishing the almost complete accord of his principle of universal gravitation with the data of minute measurement. The historian has also told us of the effects of these discoveries on the progress of general enlightenment: how, after the profane hand of Copernicus had set our proud earth, the object of heaven's most intense concern, in ignoble and servile attendance on the sun, after Tycho's comets had broken the sacred celestial spheres and Kepler's calculations had shown the imperfection of

divine celestial order, and Galileo's telescope had exposed the spotted surfaces of a changing sun and time-worn moon, the Newtonian astronomy revealed the whole heavenly realm as a dark and limitless emptiness wherein dead matter moved under the impulse of insensate forces — and thus finally destroyed the poetic dreams of ages. These hints are enough. The new science of mechanics concluded a veritable revolution in human thought: and then as always men paid a bitter price for knowledge.

The third and final stage in the development of scientific theory is that which has made possible the mechanical interpretation of all those physical phenomena which the natural philosophers of the Renaissance, to whom they were still not clearly comprehensible, called subtle: the phenomena of warmth and light and color, of magnetic and electrical disturbance, and of chemical change. The history of this bold extension of the mechanistic scheme of thought, which made all physical and chemical phenomena — phenomena as mysterious to Galileo as they were to Archimedes — not only intelligible but predictable, is altogether too rich in fact and idea alike to be summarized in the meager sketch which would be here permissible. Unlike the history of mathematics and that of mechanics, it describes the development of many separate kinds of representation, adapted to the description of widely different types of natural change: representations which were derived from hypothetical premises in-

dependently conceived to explain particular natural groups of phenomena, and which were coördinated only after all had been extensively and minutely elaborated. We speak today of the sciences of physics and chemistry, or even more generally of physical science, because a single scheme of theoretical representation permits us — or has until very recently permitted us — to view the whole range of occurrences in the inorganic world as the complicated effects of similar mechanical causes definably interrelated. It was not until the nineteenth century, however, that this unitary representation became possible. Historically, therefore, we are compelled in describing this last phase in the development of scientific theory to treat it as the development not of one science, but of many: the sciences of sound, of heat, of light, of electricity, of magnetism, of the structure of matter and of chemical change. And if, disregarding the advantages of the historical view — which permits us, so to speak, to study a subject not in mere temporal cross-section but in all its four dimensions at once — we attempt to describe even the outlines of present physical theory, we are no better off. Its rich diversity persists; for though theory has made phenomena intelligible, it has not essentially simplified them. In the present brief discussion it has been impossible to present the meagerest outline even of mechanical theory. This particular subject could be slighted without remark, for not many are interested in mechanics. It is otherwise with physical theory, since this presents that modern scientific picture of nature which almost universally compels our fascinated interest. Nevertheless, this

also must be slighted, for the same reasons many times repeated. Our consolation, meanwhile, lies in this: that the actual description of the theoretical representations of physical science is quite unnecessary to a general understanding of the habit of thought which has produced them. Various though these representations are, they are all, in so far as they are complete or physical, elaborations of one fundamental form of conception. In a word, they are atomistic.

Universally, the theoretical depiction of all those phenomena which are apprehended otherwise than as pressures, motions, and impacts is atomistic. In the first place, to make our knowledge of such phenomena quantitative, we always study them with reference to changes geometrically measurable which they undergo in various material systems (as in the case of light), or to changes in the groupings of masses which accompany them (as in chemical transformation), or to perceptible mechanical effects which they occasion (as is quite generally the case), excluding from consideration so far as possible, excepting for purposes of identification, all other experience concerning them: and this having been done, we conceive these several types of change as the aggregate results of a redistribution of motions among the invisible particles of which we believe the substances involved are composed.

The notion that matter is made up of countless invisible particles is very ancient indeed; probably primitive, for it is immediately suggested by a variety of commonplace experiences. The essence of scientific atomism is not this simple idea, nor even the quantita-

tively exact conceptions of material composition which the laws of chemical change permit us to derive from it. These conceptions are, of course, basic; but in themselves they would be of very limited scientific significance and importance. It is the conception of atomic swarms as mechanical systems, the internal energies of which may be transferred from one to another and thus be perceptually transformed, or which may by combined effect produce movement in ponderable masses and thus become measurable — it is this conception which gives to atomism its highest scientific value; for it is by the interconnected theories which elaborate it that physical science is unified as an extended science of mechanics.

The fundamental concepts of scientific atomism were clearly defined by the Greek philosophers Leucippus and Democritus nearly twenty-four centuries ago. The genesis of their theory, which involved many elementary problems of conception, suggests so clearly the essential character of our present physical theory as a scheme of representation deliberately selected rather than intuitively imagined, that its history is instructive to a high degree. It is well worth while, therefore, to remark the more important phases of this genesis. For a hundred years or more the predecessors of Leucippus and Democritus had been seeking to establish a scheme of conceptual representation which would make the world of nature intelligible. These were the first of all thinkers whose temper encouraged and whose circumstances permitted them to disavow those long-established animistic beliefs which for ages past had confined the

active thought of men to practical affairs alone. They rejected their gods, as figments of a childlike imagination; and looking out upon an amazing world with minds set wholly free, or nearly so, asked themselves, then: what *is* the nature of things? — what survives the gods? — what in the actual world is primary, fundamental, the basis of reality and of understanding? Their answers to this large question were various; and in the conflict of ideas which ensued, the question itself, as is always the case, became more clearly defined. It had two aspects, quite blended in their thought, while we would now (for better or for worse) distinguish. First, wherein lies the sameness we must find in this rich diversity of experience — the unity in multiplicity — the definable in the chaotic — the permanent in the changeable? And also, how is it possible to understand? — what form of representation in thought will make the world intelligible? It was all one question: its last expression is that which a scientist would now prefer by which to define its essential character. These men, starting with nothing, were building experimentally successive schemes of thought in terms of which they hoped to understand their world; and each scheme, in so far as it fitted in with experience, and the more certainly as it embraced wider reaches of experience, *was* reality: what else?

To Thales of Miletus, the earliest of these philosophers, the whole world was derived from water. To his younger fellow-townsman, Anaximenes, it appeared more probable that it had developed out of air; for air, unlike water, seemed limitless and inexhaustible, and moreover — the possible thought in both con-

jectures may here be glimpsed — one might actually observe the transmutation of air into water in clouds and rain, or of water into earth and air by evaporation. The more subtle Anaximander, however, rejected all such simple ideas. It seemed to him that a primary existence could not be identifiable with any of its tangible forms: it must be not only eternal and infinite, but as we should say, abstract. We possess but meager fragments of this earliest scientific thought; and it is, consequently, hazardous to attempt its too minute interpretation. It would appear that these men were seeking a fundamental existence in what we call matter. But this is not exactly the case; for we know that their primary stuff was matter and activity at once. Their water or air or protyle (let us say) was also an aliveness: it moved and changed of itself, spontaneously. This idea has persisted in scientific thought until today: it was involved in the Aristotelian conception of the world, and thence has been transmitted to us as vitalism. It is, if you please, a biological or animistic way of looking at things.

The next most distinguished of these early thinkers, Heraclitus, initiated a different habit of thought, by emphasizing not the substantial, but the dynamic aspect of the supposititious primary existence. He envisaged the world not as permanence diversified by spontaneous change, but as perpetual change which produced occasional and only apparent permanence by some sort of constant or cyclic motion, like that of the river or of the whirlpool. To him the most important consideration in the study of nature was not substance, but process; and in particular, regularity of

process. This attitude of mind has been more productive of fertile conceptions than the preceding. It foreshadows, as one can readily see, the conception of natural law. Pythagoras, the father of all mathematicians, followed Heraclitus with the equally fertile conception that the study of quantitative relations was essential to a scientific understanding of nature: and his school developed this conception so far that they practically determined the tenor of all later productive scientific thought. In its later phase, Pythagorean speculation succumbed to its original taint of mysticism: in earlier years, however, it was predominantly rational, and even experimental. Its theory of monads was the first scientific atomism — an atomism of infinitesimals. This, it should be remembered, was as much a theory of nature as a scheme of conception, for the actual and the intelligible were still not sharply distinguished in philosophical thought. As such, it was shown by Zeno to be untenable: and his criticism led directly to the formulation of the theory of Leucippus and Democritus, the essentials of which are precisely those of our present atomistic representations.

To summarize briefly the relevant aspects of their thought, it appears that one or both of these philosophers had become convinced that any conception of nature consistent with experience and therefore credible or plausible as a representation of reality, and fertile in the organization of knowledge, must picture both permanence and constant change, for the world is both permanent and changeable; and both sameness and variety, unity and multiplicity, for its variety and

multiplicity are obvious facts, and neither has comprehensible meaning unless there is postulated an underlying similarity which makes comparison possible, and an ultimate unity which is approached by successive correlations of knowledge. Its multiplicity also must be that of continuous magnitudes, as Zeno had proved; and finally it must in every aspect be quantitatively definable, for quantitative relation was also in the nature of things, as Pythagoras had pointed out and as geometry clearly demonstrated. An earlier philosophy, that of Parmenides, had warned them emphatically that the unity to be postulated must not mean universal oneness, since this conception implied a complete unchanging sameness, which not only made all phenomena illusory, but which was in solemn truth unthinkable, whatever a philosopher might think he thought about it. But the corresponding conception of a fundamental uniformity would be valuable, if it postulated not the homogeneity of one complete existence but the substantial likeness of many separate existences. Anaxagoras had already conceived the world as a plurality of elements qualitatively different; but this representation obviously begged the whole question of the nature of qualitative change, and amounted almost to an abandonment of the attempt to find any sort of uniformity in diversity.

The atomists therefore postulated, first, a plurality of existences, the relative motions of which would account for changes of all sorts; and since many varieties of change were imperceptible as motion, they conceived these existences to be invisible. To preserve the qualitative sameness of the whole — a con-

ception which permitted hypothetical explanations of diversity in terms simple, comparable, and therefore to any degree generalizable — they made these existences, their atoms, identical in substance; and this, as had been foreseen, made it necessary to attribute all differences of quality to their differences in shape and size. The world as thus conceived, then, consisted of invisible atoms in perpetual undirected motion, qualitatively alike but different in shape and size, which collided and adhered, broke apart under impact and recombined: a world of one primary substance, minutely divided into parts not infinitesimal but continuous, which differed among themselves only geometrically, that is measurably, and which nevertheless might be infinitely various either singly or in aggregates; a world in perpetual unoriginated internal motion, undergoing countless varieties of change by combination and separation of its ultimate elements. It will be noted that this atomism originally involved no specific qualifications whatever: it was, that is to say, a scheme of thought which met all necessary general requirements, and was yet capable of whatever precise definition the data of measurement might suggest. It was, moreover, a type of representation the elaboration of which would in the first place be wholly kinematic, but which was capable of mechanistic development; a representation wholly quantitative, in terms of which all sensible qualities, all warmth and color and flavor, all the rich content of sense awareness, would be conceived in terms of geometrical form and motion alone, or — anticipating its further development in a direction which the later Epicureans

actually attempted — in terms of form and motion and mass.

Thus the early Greek philosophers, in the period which preceded what Christian historians call their Enlightenment — that is, while they were still in the habit of reasoning acutely without thinking much about it, being as yet more interested in experience as a whole than in themselves — determined from general considerations alone, that *form* of representation in thought which the world of nature must assume if it is to be consistently conceivable, and with the growth of knowledge more clearly intelligible rather than more confused. It was a very remarkable achievement, prophetic of fact as we are now aware. With the Greeks, however, it remained an empty form, for they lacked the empirical knowledge with which to fill it in. Democritus elaborated it, by various unsubstantiated conjectures somewhat vague and unconvincing, as a complete materialistic philosophy. As such it was repugnant to the humanists of the moral and religious Platonic school, who ignored it; and after the biologist Aristotle also rejected it, primarily because it failed to describe the phenomena of life, it sank into oblivion. The Epicureans, whose antagonism to the prevailing religious thought of their time induced them to revive the theory, were incapable of developing it scientifically; but the Roman poet Lucretius, in his immortal *De Rerum Natura,* made its magnificent picture of the world vividly fa-

miliar to all cultivated men, and ensured its transmission to us. During the religious middle ages, the later philosophical thought of which was completely dominated by an agreeably modified Aristotelianism, there was naturally very little interest in materialistic conceptions; but after the revival of science in the seventeenth century, atomistic interpretations of phenomena, still somewhat indefinite and frequently confused by loose Pythagorean speculations, became common enough. Gassendi definitely reformulated a complete atomistic philosophy, and Leibnitz also indulged himself with analogous conjectures wholly his own; but neither those nor similar metaphysical efforts had any constructive effect upon the progress of science, excepting in so far as they assisted in a general way to inculcate similar habits of thought.

The representation of matter as consisting of aggregates of small particles appears in various scientific works of this period. Galileo's theory of solid cohesion, for instance, Descartes's conception of cosmic vortices, Newton's representation of the constitution of gases and Boyle's corpuscular theory of chemical change which pictured the ultimate particles of elementary substances as combining by cohesion, all involved a sort of atomism which with the progress of knowledge became more and more distinct; but it was wholly qualitative, and is not, therefore, to be considered theoretical in the Greek sense. Indeed, these representations, in comparison with those of the ancient philosophers, were quite primitive; and were such as might well have been conceived had there been no philosophical atomism at all.

At a later time, Newton's famous corpuscular theory, which represented a ray of light as a stream of imponderable atoms shot like projectiles from the luminous body, gave opportunity for the development of more precise conceptions, which Newton himself was quick to seize. Descartes's prior theory of the reflection and refraction of light had involved similar basic ideas which he had applied geometrically and brought partially into accord with the phenomena. Newton's theory was incomparably more inclusive. Based upon the assumption of forces of attraction and repulsion between the corpuscles of light and those of the media which transmitted it, it was consistently developed as an elaborate physical theory which successfully coördinated a large variety of complicated phenomena; and throughout the eighteenth century was accepted on its merits as superior to the contemporary wave theory of Huygens, which was wholly kinematic, and involved no definite atomism. The analogous corpuscular theory of heat, developed somewhat later, which ascribed the phenomena of fusion, dilatation, and evaporation to the intrusion between the ultimate particles of matter of an imponderable caloric, the atoms of which were attracted by matter but repelled by each other, was equally successful in yielding consistent conceptions of all the measured thermal phenomena which were known before the close of the eighteenth century; and like the corpuscular theory of light was capable of quantitative development, though the phenomena it coördinated were not, in the nature of things, so minutely observable, and thus did not necessitate a comparably precise interpretation.

It is worthy of remark that these two theories, which involved the first scientific development of atomistic conceptions of the philosophic type, were not, properly speaking, dynamic. They included vague conceptions of force, and were in this sense mechanical; but the mass relations thus involved, which by hypothesis were imperceptible, remained indefinite.

At the beginning of the nineteenth century the corpuscular theory of light was forced to give way to the undulatory theory of Young and Fresnel, not primarily because it was utterly incapable of interpreting the complicated optical phenomena then known, but because in order to do so it was forced into a multiplication of hypotheses which made it comparatively very awkward and problematical. The caloric theory, on the other hand, though it was able to evade the criticisms of Rumford (who attacked it on the ground that, when heat was generated by friction, it was evolved in undiminishing quantity out of all proportion to material transformed and in rough correspondence with the work performed) was quite unable to meet the criticisms of Davy, whose crucial experiments, despite their imperfect character, demonstrated the mechanical generation of heat under circumstances which, according to the theory itself, permitted no available source of caloric. The mechanical theory of heat which finally took its place, however, was equally atomistic, since it defined heat as the irregular movement of the ultimate particles of material substances. The contemporaries of Davy criticized this mechanical conception, and justly, because as originally conceived it was indefinite and

correspondingly infertile in suggestion; specifically, because it yielded no precise ideas concerning the nature of heat such as might be quantitatively developed. It was not long, however, before this criticism was fully met.

The first modern atomistic theory which was completely mechanical was the kinetic theory of gases. This theory was first enunciated by Daniel Bernoulli in the middle of the eighteenth century. It pictured a gas as consisting, not of particles in quasi-static equilibrium held apart by repulsive forces — the usual representation in his day, consistent with the caloric theory of heat — but of particles in rapid and undirected rectilinear motion; a swarm of invisible elastic projectiles, which moving quite independently, shot past one another, collided and rebounded at random, and thus quickly penetrated into any available space, or by impact against the walls of their container exerted upon it a pressure which increased with diminution of volume and with rise of temperature. This conception, more vividly than any other, recalls that of the old philosophical atomists. It lacked their conception of atomic form, which indeed could not be justified by the phenomena then known; but it was also richer than any preceding atomistic representation, since, because the gas particles had mass, it was completely mechanical. It is clear also that it provided the conceptions necessary to repair the defects of the original vaguer theory by making it quantitatively definite. In brief, change of temperature was measured by the expansion of gases by heat; this expansion, against pressure, meant work

performed; according to the kinetic theory this work was the effect of a bombardment by countless gas particles, and was therefore the measure of change in the total energy of their translatory motion, which could be defined as the summation of the kinetic energies of individual particles, expressed in terms of their masses and mean velocity.

As a consequence of the long persistence of general representations inconsistent with this conception of heat — which, even after Davy had demonstrated their insufficiency, still held their ground as familiar conceptions which remained plausible and useful while experimental justification of the mechanical theory was lacking — Bernoulli's ideas were for many years ignored. They were revived and extensively, though to some extent imperfectly, developed by Waterston toward the middle of the nineteenth century, but were still ignored; and it was not until after Joule had conclusively demonstrated the measurable invariability of the mechanical equivalent of heat by its exact determination in systems of widely different character undergoing thermal change, that, once more developed, they were finally accepted by all theoretical physicists. In the second half of the nineteenth century, after Joule, the mechanical theory had shown itself with reference to thermal phenomena in the gross to be capable of valid formal development; and the general conception of energy derived from it soon unified theoretically the study of all varieties of physico-chemical transformation. Consistently with these advances, the kinetic theory of gases was itself independently reformulated and developed by Clausius,

Maxwell, Boltzmann, and their successors, as an elaborate mechanical representation according to which thereafter not gases alone, but liquids and solids as well, were conceived as dynamical systems to which the laws of molar mechanics were universally applicable. Thenceforth in the scientific mind an invisible mechanical world existed, within the world of visible and tangible motion: a world wholly similar which, however, was apprehended not immediately by sight nor touch, but rather through the perception of warmth.

While these new theories were being laboriously developed a new type of atomism arose: not among the physicists, but among the chemists, whose work since the early years of the eighteenth century had been conducted more or less independently. At the beginning of the nineteenth century the French chemist Proust had discovered the law of definite proportions: in other words, had proved by a long series of precise and consistent quantitative chemical analyses that all elementary substances, when they combined to yield new homogeneous substances, did so in fixed and invariable proportions by weight. His data were sufficient to establish a second generalization of equal consequence, which he missed but which was later demonstrated by Dalton: namely, that when one elementary substance formed with another more than one such compound, the several weights of the second which combined with a given weight of the first were in simple arithmetical ratio. Thus, nitrogen forms five compounds with oxygen; and in these compounds the weights of oxygen which combine with

a given weight of nitrogen are in the ratios 1:2:3:4:5. Dalton was quick to interpret these results atomistically. Without such interpretation, indeed, they seemed inexplicable. He assumed that the ultimate particles of elementary substances, which he called atoms and pictured as little spheres, had characteristic and invariable masses; and that therefore when aggregates of these atoms combined they must necessarily form compounds in the ratio of these atomic weights or of their multiples.

Such was the genesis of the chemical atomic theory. Its high plausibility and its promise of fertility were immediately recognized. The first necessary step in its development was clearly the determination of the atomic weights: more precisely, the ratios of the atomic masses — for the actual weights of these extremely minute particles were, of course, not then measurable. It was a relatively simple matter to determine the combining ratios, provided pure substances could be prepared and the technique of analysis sufficiently perfected to yield results acceptably precise. To discover which of these ratios were atomic weights, and which were multiples of these weights was, however, a very puzzling question. Dalton himself resorted to the method of simplest arbitrary presumption, assuming that if only one binary compound of two elements existed, so far as known, its smallest particle was a compound of two atoms — and so on. This was obviously only a working hypothesis: the problem was in fact exceedingly difficult; so difficult that half a century elapsed before it was satisfactorily solved by an accumulation of inductive inferences

derived from the study of various phenomena. Its interesting history cannot be entered into here. One phase of it, however, demands our attention.

Shortly after the first publication of Dalton's hypothesis, the French physicist Gay Lussac had discovered that gases combined chemically, under the same conditions of temperature and pressure, in definite ratios by volume. It was a natural inference, supported by the similar physical behavior of different gaseous systems, that equal volumes of different gases contained the same number of atoms under like conditions. The volume ratios, however, were such that if this hypothesis were accepted it would be necessary to assume that the atom was divisible in chemical change, and this was contrary to the primary assumption of the atomic theory. This difficulty was met a few years later by the Italian physicist Avogadro, who assumed that in some elementary gases the ultimate particles of the free substance were double atoms. When, after some delay, this hypothesis was generally accepted, the atom, for elementary and compound substances alike, was distinguished from the ultimate particle of the free substance.

Henceforth, therefore, there existed in the scientific mind, quite generally, two orders of invisible particles: the one, which we now know as the molecule, being the smallest particle of an actual substance, the other, the atom, being a constituent of this. The molecule, then, was considered a system of atomic bodies, probably in motion, which was disrupted or rebuilt in chemical change. The movements of whole molecules, perceived as heat, might produce mechani-

cal effects in molar masses: similarly the motion of the atoms within them, the effects of which were made apparent by the qualitative changes of visible systems which marked the transformation of one kind of molecule into another, might produce acceleration or retardation of the molecular masses themselves, perceptible as the evolution or absorption of heat; and finally, this heat evolved or absorbed, which could be measured by its possible mechanical effect, would represent the loss or gain of the system transformed in energy of atomic motion or stress within its molecules. Thus, by the representation of one atomic system within another, it became, in anticipation, possible to interpret chemical change or change of substantial quality, as well as heat, mechanically and therefore quantitatively in terms of distance and direction, time and mass. And meanwhile, the ratios of the atomic masses being determined, those of molecules were likewise known, it having been established that no loss or gain of mass occurred in isolated systems as a consequence of chemical change. In detail, therefore, as well as in the gross, the mechanics of both these invisible systems were made susceptible to complete definition, whenever the further study of phenomena might supply data which would reveal more precisely the character of molecular motion, and that of atomic motion or stress within the molecule.

The chemical atomic theory in its later development has suggested, in addition, further possibilities in the extension of atomistic representation which, very roughly and uncertainly as yet, but encouragingly, sustain the hope that molecular constitutions

may actually be determined. Early in the nineteenth century the Swedish chemist Berzelius, whose labors were the most effective of all in developing the atomic theory, established beyond doubt a fact already suspected: that there were substances of the same composition and molecular mass which had different properties. The only possible atomistic explanation of this phenomenon was that their differences were due to different arrangements of atoms, either static or dynamic, within their molecules. Since his day, especially as a consequence of the very rapid extension of our knowledge of the compounds of carbon — among which those that have been isolated and identified are already more numerous than all other known compounds taken together — a very large variety of similarly isomeric substances (as they are called) have been discovered. It is customary in organic chemistry, the science of the compounds of carbon, — and in the case of isomeric substances it is necessary in order to avoid ambiguity — to represent molecular compositions by elaborate diagrammatic formulae which picture the molecule, consistently with its chemical behavior, as containing nuclei of relatively persistent groups of atoms. The permissible variation of these representations has become more and more restricted with the growth of chemical knowledge; and they thus pass by insensible gradations into forms which are to some extent physically interpretable. These diagrammatic formulae, originally merely symbolic, thus come to represent with increasing probability possible types of actual configuration — by no means precisely geometric but gradually approaching

such definition. The extreme development of this sort of formulation is reached in the representation of certain types of isomers, which cannot be distinguished excepting by formulae which are mirror images of each other; the development of which, still guided by the phenomena of chemical behavior, compels their depiction by diagrams in three dimensions. The complicated detail of these representations cannot be understood nor their possible significance discussed without reference to extensive chemical knowledge, and cannot therefore be here considered. The fact that they are necessary for the intelligible description of molecular composition, however, is too suggestive to be disregarded. They are, as it will be realized at once, the modern analogues of the undetermined atomic shapes of the old Greek atomists. They are not physical models by any means; but they may not impossibly be transformed into such models if physics shall be able to construct, in the probably distant future, a dynamics of atomic systems.

The final phase in the development of scientific atomism is contemporaneous. There are few who have not made themselves more or less familiar with those startlingly dramatic discoveries of recent years which have yielded unequivocal evidence that the atom itself is a system of still smaller bodies. A third invisible world has been revealed, within the atom and external to it — a world of electric particles exceedingly minute, moving in freedom with velocities so extreme that their energy is sufficient to make them even singly observable, or vibrating within closed systems quite insensibly. These particles we call

electrons. In free movement they are observed as electrical discharges: traversing space in countless swarms, shattering the air in lightning strokes, streaming or otherwise moving progressively between the atoms of conducting metals, disintegrating matter by impact, generating light and the penetrating invisible radiations which we call X-rays. Such discharges, controlled and manipulated by the effects of separate electrical fields upon them, and otherwise examined by the measurement of their own various effects in altering the character and behavior of familiar material systems, have been forced to betray their nature by their activity. The masses of the electrons, the magnitudes of the electrical forces which they exert, the manner of their interaction, have all been determined. It has been observed, furthermore, that these electrons are set free by the spontaneous disintegration of radium and certain other elements, and that in this process new elements of smaller atomic mass are formed; that certain elementary gases may be similarly transmuted by bombarding them with streams of electrons otherwise generated and very swiftly moving, and that in all such changes very large amounts of energy are released by the transmutation of minute quantities of material.

These phenomena prove that the electrons are constituents of many known atoms, and therefore — inductively — constituents of all; and since the atoms of ordinary matter do not repel each other, it is inferred that within them the like electric forces which exist in the neighborhood of all free electrons are exactly neutralized. With reference to the behavior of

electrically active bodies of sensible dimensions, this phenomenon is ascribed to the existence within the atom of electrical forces of opposite influence, the total effect of which is equal to that of all the electrons. The foci of such forces, with reference to which they are measured, are called charges. Conventionally, the charge of the electrons is called negative. The opposite or neutralizing positive charge is conceived as that of a central mass or nucleus, around which the electrons revolve in orbits, like planets around the sun, excepting that there may be more than one electron in an orbit. A large amount of consistent evidence supports this hypothesis, which in recent years has assumed a precisely quantitative form in the description of the two simplest atoms — those, namely, of hydrogen and helium. Further evidence permits us also to deduce the number of orbital electrons in each atom, and hence, the electronic masses being known, to evaluate the masses of the several atomic nuclei. It is thus inferred that nearly the whole mass of every atom is centered in the nucleus. In electrical discharge through gases streams of positive electricity are in fact observed, the particles of which are of atomic mass: and radio-active elements emit similar streams of corpuscles, which inferentially are fragments of their nuclei. Finally, it is quite evident that consistently with all the evidence which supports these and many other related inferences, both luminous and invisible radiations are generated by the motion of electrons within atoms whenever, as it seems, their orbital motions are violently disturbed.

This meager sketch will be sufficient to indicate the

general character of this last phase of atomism, which not only demonstrates the electrical constitution of matter but reduces the number of its unanalyzable constituents from nearly a hundred to two, converting thus a pluralistic material universe into a duality. It explains the generation of light and more penetrating radiations as chemical atomism explained the qualitative transformation of matter, but very much more minutely; quite as molecular atomism, in earlier physics, explained the nature of heat: by conceptions completely dynamic.

The phenomena of rapidly moving electric charges introduce new and puzzling problems into the realm of mechanics itself; and these, together with related problems still more difficult respecting the nature of radiation, are causing at the moment a not inconsiderable confusion in theoretical representation, the outcome of which will doubtless be a revision of fundamental conceptions. These matters may be no more than mentioned here. It is sufficient, with reference to our present interest, only to remark that no such revision, however radical it may be, can invalidate the correlations of classical molar or molecular mechanics or those of chemical atomistics, each within its own domain, or the general theory of energy that binds them all together; for these with the passage of time have been confirmed by such a wealth of evidence that they have become factual rather than theoretical. More highly developed theory will surely effect a more minute analysis of their detail and thus revise them; but in their generality they will remain true. Just as the Euclidean geometry will always be, one

dares to say, in complete accord with all but rare experiences, so these representations will remain in similar accord with all the terrestrial phenomena of electrically neutral systems. Our theories, like the facts which sustain them, elaborate themselves, becoming more and more minutely representative and precise, fuse and blend with internal readjustment of relations into more and more inclusive generalizations. They, like fact, are in a state of flux, approaching, we hope, a final completion in detail; but whether or not we shall ever discover that Universal Form which will correlate consistently all future possibilities of knowledge, our successive partial correlations will still be true within the range of the approximately determined phenomena which they adequately describe. They may not, in the distant future, be most usefully expressed in the terms we now employ, but they will still be true in substance; and all experience so far points to the probability of their remaining useful in their present form.

The immediate difficulties of theoretical physics are of a sort which is very familiar in retrospect: every readjustment of our more general conceptual schemes has been attended with similar disturbance, frequently prolonged. We may well afford to let half a century elapse before we become impatient. At the worst, we shall merely fail to blend electrodynamics with the rest of physical science; and except to the metaphysical mind this would be inconvenient rather than tragic. Our passion for unification means scientifically only our urgent desire to understand more clearly. We are now seeking to attain this unification in physi-

cal science by establishing new formulations of interdependence between the spatial and temporal aspects of motion which, separated so long in thought, we are accustomed to think of as independent. In ordinary experience they are so, truly; but there are phenomena which seem, though not certainly yet, to force their recomposition in theory. Thus men are beginning to speak philosophically not of space and time but of space-time, and not of things, but of events. The mathematical ingenuity of these thinkers fills scientists themselves with admiring amazement; and it is wisely encouraged, for though their efforts may be premature, it is always well to be prepared. Meanwhile, of course, ingenuous people speak of the destruction of classical physics, and the downfall of materialism (by which they mean, without knowing it, our customary pragmatic mechanism) just as, not so many years ago, when radioactvity was discovered, they spoke of the destruction of chemical theory. But there is no more destruction going on now than there was then; only reconception and readjustment: and if these new formulations are shown to be the simplest which are adequate to establish a unitary theory, and yet remain as difficult to master and to utilize as they now appear to be, there will be many who will prefer to live scientifically in a pluralistic universe — and small harm done.

We live in a pluralistic universe anyway. For even a unified mechanistic theory could not, at present, however subtly it might be conceived, embrace and thus explain the phenomena of life; nor could it now summarize even within its own physical domain more

than a part of our wealth of scientific knowledge. The greater bulk of all our knowledge remains, and while it grows must always, probably, remain, in large measure quite untheoretical. While this is the case, it is impossible to predict that its more minute analysis will betray no further inconsistencies in our scheme of representation; and without this assurance, the assertion that the world is one would be pure dogma. That part of our knowledge which theory embraces, moreover, is conceived in only one if its multifarious aspects: as mechanism. Our world is pluralistic not only because its phenomena are incompletely unified by theory, but because it may be apprehended in many ways and interpreted from as many points of view as there are vital interests to serve. Our knowledge is a part of our life, and shares its persistent diversity of function. Facts are, therefore, many-faceted: they reflect by corresponding planes a variety of coördinated aspects, which blend in contrasting systems of thought that are irreducible and even conflicting. Thus it is not only because facts are necessarily the basis of scientific thought that the scientist keeps them forever before his eyes; he does this also because they are more interesting than ideas, are pregnant with unimaginable possibilities. They are the richer part of life: they are wonderful and beautiful and terrible; they glow and tingle and burn and ring in the brightness and warmth and music of our vivid world of sense; they are alive with our own life. All this means that the scientist is not a mere thinker who dwells

> "Where entity and quiddity, the ghosts of defunct bodies, fly."

He is a creative artist. And when he is in his laboratory or in the field, upon the mountains, within the forest or at sea — discovering new energies, new matter, new life, new worlds, or discerning new wonders in old familiar things — isolated with his puzzling, fascinating, exasperating and utterly satisfying facts, and by God's grace for a little while aloof from the fret of human squabble and strife and care, he becomes the romanticist's simple child of nature in very truth. There are other joys than his but none more keen.

Beyond theory, then, there is room for a science of immediate experience, richly complete. This science knows the world not abstractly, but in its wholeness, as aesthetics knows it, or religion, which supplement and give new value to knowledge. But it is the business of the scientist to provide knowledge itself, and to guarantee its soundness. His theory is the guide of his intelligence. He cherishes it, therefore, and develops it extensively and minutely; for it is necessary, if he is to find his particular joy in life by doing his hard work well, that he shall be at all times as intelligent as possible.

IV

SCIENTIFIC HUMANISM: A COROLLARY

IV

SCIENTIFIC HUMANISM

AMONG cultivated people it is now quite generally conceded that scientific studies of some sort are desirable elements in any liberal education — that is to say, in general education which is not restricted to vocational or professional fields, but leads toward an appreciative understanding of our culture as a whole. Even by the solidly conservative, the fact is recognized that any comprehensive study of our culture, at least of our common culture, would now be seriously imperfect that completely disregarded the influence upon it of those wonderful discoveries which, they are aware, have given us electricity, the airplane, psychological complexes and all that sort of thing. It might be admitted, they would suppose, that an understanding of scientific laws, formulas and so on is not actually essential in general education; but certainly no man today would consider himself adequately informed who failed to appreciate their really remarkable, and most interesting, effect upon our civilization.

Common opinion supports this liberal view — in principle. It is, however, considerably more emphatic. All men of affairs have long since been fully convinced, observant scholars are already beginning to suspect, and the plain practical people uncompromisingly assert that scientific studies — not of some

sort, but of certified Grade A quality—must, in the future, constitute the very foundation of liberal education; that it is no longer possible to consider any man even decently prepared to begin his higher education, much less to call him informed, who cannot for lack of knowledge understand more than superficially the physical world of which he is a part, the structure and functions of his own body and mind, the mechanism of his complicated civilization, the social forces which animate it, and the character and tendency of the dominant thought of his age. In other words, plain people say, it is a patent fact which the cultivated classes have come very tardily to realize, after staring it in the face for three centuries or more, that if the educative process means the cultivation of the critical understanding — and this is the obvious implication of all modern definitions — then it is by no means a matter of indifference what its substance shall be. It is no longer permissible to maintain that training is training, and that one may become cultivated by studying anything seriously. This specious argument, with which the cultivated aristocrats of a former day so cleverly misled their ingenuous public, must now be precisely inverted; for we are wiser now, and know full well that although learning may to advantage assume many forms, its actual matter must be significant knowledge: that is, science. To understand the world of nature, which is the world of Necessity, by continual adaptation to which the course of every life is ultimately determined; to understand the intricately adjusted but imperfect mechanism of this adaptation

which our civilization embodies; to penetrate into the unconscious motives of human behavior, in ignorance of which our subtlest analyses of social relations are defective and misleading and our artistic appreciations merely emotional; and finally, on the basis of this and like information to construct a philosophy which shall provide a theory of values and rules of thought and conduct in accord, not with habitual prejudices nor whimsical ideals but with the facts of experience — these, they argue, are certainly the most essential of all educational purposes, and not one of them can possibly be fulfilled excepting through the acquisition of scientific knowledge.

Even in cultivated circles these arguments are now beginning to prevail; but the actual incorporation of scientific studies in humanistic curricula is still resisted, not always impassively, and the complete reorganization of our educational programs which unqualified acceptance of the extreme demand would certainly necessitate is not yet possible. All habits are tenacious, habits of thought notoriously so. The establishment of science as the basis of our scheme of liberal culture asks too much of a generation whose own education was guided by a wholly different, indeed a contradictory, theory of values. Scientific humanism is a conception that would have been grasped with difficulty by our predecessors. The higher education which they particularly valued was appreciative rather than profound. Their serious study of our most vital human interests was almost wholly professional: it was considered the proper concern not of the merely cultivated, but of the learned; and humanistic mo-

tives sufficiently philosophical to compel its undertaking were rare even among scholars. This, however, is no longer the case; and the fact is recognized, even if its inevitable consequences are for the time evaded.

A new standard of general culture has been set by the more exacting demands of contemporary life. The intensification of activity in every field of endeavor and the concentration of effort which it compels, the more thoroughgoing training which is now necessary in preparation for all vocations and professions, and the greater diversity of aptitude which is developed by the practice of each of these, appear considerably to have improved the critical acumen of all intelligent people. In any event, their serious concerns are more intellectual than formerly, less imaginative; critical literature has been more widely popularized, and as a consequence a more considerable fraction of it is commonly understood. It is probable, also, that a larger number of intelligent men have developed serious interests of a purely intellectual character: this is certainly the case among the more highly cultivated. The humanistic literature now accessible to everybody is not only particularly diversified, but as a consequence of its thoroughgoing assimilation of anthropological facts and theories, looks very scientific and sometimes even depressingly so. This literature is widely read and thoughtfully pondered not only by the cultivated but by the unlearned. Its substance is common property; even its jargon has found its way into common speech. To the most reluctant, therefore, it is now evident enough

that the cultivated man, unless he is to isolate himself completely from the world, must become at least acquainted with humanistic interests of another sort than those which he has cherished heretofore. And it is equally clear, that if he is to maintain his former position in the esteem of his contemporaries and in his own esteem, if he is to justify the deference which is still quite honestly accorded him by rendering the same high service that his predecessors rendered in their generation, he must acquire, not keener intelligence and deeper wisdom than that which their world demanded, but most certainly a more extensive and much profounder knowledge: scientific knowledge.

It will be well worth while to amplify this brief survey. It does not depict, as the scientifically educated will almost certainly believe, a situation already outlived. Those who have enjoyed the opportunities of free elective education are slow to appreciate the persistent effect of those long established habits of thought which still inhibit to a high degree, not the progress of science indeed, but the dissemination of scientific knowledge and the inculcation of a scientific spirit among men of superior endowment — that is to say, among those whose influence upon the tendency of common thought would, if wisely directed, be most effectively beneficial. It is less than two generations ago that our higher education became fully secularized and still more recently that its scope was extended sufficiently to permit its thorough liberalization. The process of this liberalization is not yet by any means complete; nor will it be until our standards of higher culture are raised considerably above their present

level. In our better institutions of learning today, the scope of liberal education leaves nothing to be desired; its spirit, however, needs everywhere to be much improved by the awakening, through adequate discipline, of a more intelligent understanding of scientific work and thought, and keener appreciation of the profoundly significant influence of scientific knowledge on every phase of cultural development. Only when all cultivated men participate sympathetically in this most powerful intellectual activity of their time may we hope by the intelligent control of general education to guard the superior civilization it has created against the effects of its possible impairment or injurious misdirection, and insure the continuance of its beneficial effects. The most urgent problem which confronts the educator today, therefore, is the general inculcation of scientific knowledge and understanding, particularly among men of broadly humanistic spirit by whose influence public opinion may be most effectively enlightened. It is not sufficient that the importance of scientific investigation be admitted: researches will be prosecuted with increasing ardor, whether their importance be admitted or not. The human problem is to assimilate and command, and to develop to its highest possible service the rapidly increasing knowledge and power which these researches provide. For this as well as for the minor contributory purpose of living and thinking contemporaneously, the liberally educated man may no longer neglect, even if he acknowledges, his obvious cultural responsibilities. It is a natural but dangerous common weakness to accept a good intention as equivalent to

actual performance, despite the warning of a popular aphorism universally known. A parallel weakness is that which accepts the vague apprehension of a critical situation as equivalent to its vivid realization; for the clearest possible understanding is demanded for effective action in emergency. Possibly, therefore, it will not be a wholly fruitless undertaking to attempt the presentation in some detail of an educational situation which, however generally it may be casually apprehended, is seldom clearly envisaged. Even though such presentation should appear at times somewhat familiarly reminiscent, it might still be justifiable: were it nothing more than a patiently persuasive commentary on the obvious, its possible human value would not on this account, necessarily, be sensibly diminished. Theodore Roosevelt once pithily explained himself to a not unsympathetic Harvard audience by remarking that many a platitude possesses the compelling dignity of an unregarded truth. Allowing this bit of wisdom to exercise its full effect upon the mind, it is possible, without embarrassment, to proceed:

During the nineteenth century, the very century whose labors produced our present embarrassment of cultural riches, liberal education commonly meant, not the study of the whole great world of nature, but the study of man alone; and the study of man not as the product and plaything of nature, but as a free immortal soul; and no longer as a struggling and

humble soul, working his blind way toward the light, but as an ardent soul whose thought was more important than his work, and whose love and play and dreams and songs were more interesting than his thought. By long intensive cultivation, this field of study had been converted in greater part into a luxuriant formal garden: one which to our present taste seems to have been rather too carefully trimmed, and weeded, and taxonomized, and too selfconsciously enjoyed; but none the less a treasure-land which held the rarest products of man's joy and sorrow, erudition and wisdom and aspiration: a retreat from the wearisome turmoil of the world, accessible to all who keenly enough desired, where the troubled mind was cheered and reinvigorated. Familiarity with its stimulating beauty had become the sign of good breeding; for it implied the enrichment of experience which is ordinarily necessary to the cultivation of taste, discrimination and generosity of spirit. This was the goal of our fathers' educational training: good breeding. It was primarily a moral criterion; one which embodied the highest ethical and aesthetic ideals of pagan, Mohammedan and Christian tradition. It combined the equability of the Greek, the virtue of the Roman, the generosity of the Arab, the piety and chivalry of the medieval knight, with the courage of them all; and to these high qualities the German had added candor, the French a new sensitivity and acumen, the English fair play. Scholarship gave vitality to these traditions, developed a breadth of humanistic interest which nourished them and a wisdom which justified them. Without reference to this high service, indeed,

this scholarship in itself might yield profound gratification; its liberalizing and refining influence was highly valued and its stimulation of keener thought more highly still; but its ultimate function was the development of character. The ideal which our fathers conceived (too high to be attained, excepting rarely, yet always to be striven for) is one which we cherish still and must always cherish, or reject the instinctive wisdom of the centuries; it was, however, an ideal of worth and of conduct, rather than of achievement.

The cultivation which this high standard of excellence demanded and encouraged was derived from what was called the education of a gentleman, and produced, first of all, the man of the world. This man had acquired in his youth a thorough knowledge of custom and convention, and consequently the poise which made him comfortable in any society; he had a good command of his own language, and very commonly of other languages, particularly French; he could read Latin and very likely Greek, though unlike his grandfather he rarely spoke these tongues; he was familiar with the masterpieces of modern and ancient literature, and was correspondingly informed concerning the customs, institutions and common mental attitudes of the past, had developed a discriminating taste for eloquent prose and inspiring verse, and could punctuate his equable discourse and adorn his occasional wit with apt quotation. His knowledge of the history of events was adequate; he understood thoroughly the basis and value of his own traditions and those of his country, and was as conversant with

the politics of his time as with its literature, art and music. He had studied elementary mathematics for its disciplinary value, and had dipped into philosophy and science to satisfy mild curiosity and to forestall possible embarrassment; but the field of his genuine intellectual interest was that of the humanities: history, literature and the arts. The necessary practical training for business or profession which had probably followed the period of his formal instruction had not been permitted to curtail it; the interests which it had encouraged had, therefore, been thoroughly inculcated and had survived this interruption. Thereafter, to the extent that his productive work permitted, they were revived and not infrequently cultivated anew, so that in later life his inner resources were adequate to enrich his hours of respite and leisure with the best that life could offer, at any rate to those who like himself were receptive but incurious, high-minded but self-contained.

It is still possible for one to live pleasantly, intellectually, and in a very significant way usefully, by the cultivation of the aptitudes and tastes which were stimulated and developed by this education, and by the determined maintenance of its standard of good breeding. The inestimable value of the ideals it represented — moral, aesthetic and intellectual — is not to be argued or disputed; it is demonstrated by the experience of two thousand years. One of the most serious responsibilities of the educator in our own day is to see to it that this standard shall not be lowered. The problem actually confronting him, however, is one of much greater difficulty; for it has now become

necessary not merely to defend this standard but to raise it.

That this is no mere professional opinion, based on theoretical contentions of the sort that so frequently impair the teacher's judgment, is evident enough: it may be inferred directly from commonplace observations. In recent years there has come about a subtle change in the tone of cultivated society (it is not so subtle in society at large) which indicates a significantly spontaneous diversion of moral and intellectual interest. In this society, with which throughout his life he has been most familiar and which he calls his own, the educated man whose impersonal interests are restricted to the older humanistic range feels, oddly, not out of place but somewhat detached. He mildly deprecates its freer manners: but this doubtless expresses the prejudice of habit, and may be disregarded. Quite seriously, however, he suspects, and not without growing apprehension, that he no longer fully shares in its deeper concerns. He is made to feel, insensibly to be sure, but unmistakably, almost as if — absurd though it may seem — he is living on the surface of things; out of touch with great events, the stir of which he feels but cannot grasp, the significance of which he surmises but does not clearly understand. To be out of sympathy with the significant thought of his time is against his will and desire. The mere suspicion that it may be so outrages his innermost conviction; but to dispel uneasiness he acts as he supposes any intelligent person would naturally act: he equably faces the fact, and tries dispassionately to analyze his situation.

It is easily done. He observes first of all — this is our human nature — the most displeasing change, an unmistakable deterioration in ease and facility of speech: the art of clear expression seems to have disappeared along with vocabularies and grammar. A touch of exaggeration here, perhaps; but the general indifference to art, the growing ignorance of good literature and the utter degradation of musical taste cannot be denied. There is a widespread disregard, even here among those men and women whose antecedents and opportunities were as favorable as his own, of the culture which he has most highly prized. This may be the result of a new contagion. Good society is more easy-going than formerly: a clearer reflection than his own of the great democracy from which both were derived. It no longer exhibits any extraneous aristocratic pretension. More frequently than formerly he meets among well informed and highly educated people men whose antecedents were widely different from his own, whose parents and teachers had little of his sort of culture to lose; and he whimsically admits the fact that the people at large were never much interested in its graces and refinements. This explanation, however, is not sufficient. The disregard of these refinements, which despite his self-imposed detachment he cannot pretend not to deplore, is quite general. Those of whom something better might be expected — the prejudice again, but let it pass — are not unlike the rest. And in this case the insight that a more instinctive sympathy permits forces him to acknowledge that this negligence is not the result of any demonstrable slackening of moral and intellectual

fibre; that it is, not the careless throwing away, but rather the sacrifice of a not unvalued heritage under the compulsion either of stern practical necessity or of cultural interests which are thought to be of more vital importance. The compulsion of necessity, he finds, is generally conceded: all work, and particularly the work of the well-endowed, has become more exacting; the burden on young shoulders has become too heavy. But this excuse, in the absence of more impressive evidence than that which ordinarily presents itself, will hardly be accepted by a gentleman of his school. Generously, then, he seeks to understand the other.

He observes that his world now concerns itself — perhaps, again, by democratic contagion — with a greater diversity of interests. There is more conflict of opinion, too emphatic opinion; and yet at the same time less prejudice, more toleration, not only of manners but of ideas. The range of individual curiosity seems to be very wide, but personal information and experience even pitifully restricted. There is no common universe of discourse, unless it be the news — not here as elsewhere the pictured news of scandal and of sport, but the news especially of politics and commerce; for everybody is a citizen and nearly everybody is commercial. A dissipation of thought? — but the general talk about these matters is far from trivial. Political interests appear to center in world affairs, industrial and commercial interests in social problems, and there is an unmistakable note of earnestness in nearly all discussion. Its tone is serious. The pleasant allusive interchange of thought, the whimsicality, the repartee, is seldom heard; and not, it would appear,

only because it is now more difficult. Conversation is no longer an art; it seems to have become a discipline, an awkward means of mutual instruction. General discussion never persists overlong: obviously it cannot. It gives place to the monologue, which now is actually welcomed; to question and answer; to the quiet conference of two or three who discuss weighty matters in a corner, and frequently unintelligibly, in strange technical language. These discourses, interrupted by puzzled inquiry, are hastily popularized on the spur of the moment, compel general attention, and degenerate into lectures. No matter where one happens to be — in the street, in the office, at hasty luncheon or formal dinner, at home before the fire, in the railway carriage or in church — it is all one. Everywhere and at every hour the cultivated world seems spontaneously and with cheerful earnestness to be going back to school. To what end? — but it is clear enough.

This striking change in the intellectual attitude of the onlooker, this overturn of his standard of cultural values which clearly implies something more significant than a merely capricious diversion of interest, is of course the effect of no sudden revulsion of feeling and opinion. It seems to have resulted from the awakening of a newly stimulated critical judgment, and such without doubt is the case; but the awakening has been gradual and the judgment long matured. This judgment reflects directly a correspondingly gradual change in the cultural interest of the world at large, itself the result of a century's unprecedented enrichment of common knowledge concerning nature and man. The humanistic outlook of

ordinary people is incomparably broader than ever heretofore; its philosophical basis, however vaguely it may be apprehended, is more severely rational and its educational requirements more exacting. The range of common experience has been enlarged to an extent that is not consciously appreciated. Familiarity with the new knowledge and power which was our heritage from the nineteenth century alone could blind us to its inevitable effect, not only upon the conduct of our lives, but on the tenor of our thoughts and the substance of our desires. The wilderness of nature so long and so patiently cultivated by the pioneers of science has yielded such highly flavored and delicious fruit that the ancient gardens of formal culture no longer entice us. Who would wish to imagine and to dream in a world which provides in such miraculous abundance the actual wonders and delights that surpass all imagination? What curiosity would rest satisfied with the mystery of the power and thrill of words and melodies, when it faces the limitless mystery of an earth and heaven no longer aloof and impenetrable, but half unveiled? What reflection would confine itself to the concerns of men alone, when there is revealed a glimpse of the universal laws which determine those concerns? And above all, who would labor to express his aspirations, who has at his command the means to realize them?

Small wonder that the cultivated world is going back to school. But their motive in doing this involves a purpose more serious than the gratification of curiosity and the fulfilment of aspiration. These will always remain the highest of human impulses, but they

are not the most compelling. This army of students is spontaneously eager, but it is also earnest. They feel the high adventure, like all good recruits in war; but like these others they act under compulsion, for the knowledge which they seek is not only the weapon of great achievement, it is the armor of self-preservation.

The scientific discoveries of the nineteenth century have actually remodelled the structure of western civilization. Adaptation to the conditions of life which their ready utilization imposed is not yet complete. The social readjustment which was heralded by the industrial revolution and in the midst of which we continue to live, is undoubtedly the most radical and far-reaching that the world has ever seen. The steam-engine was only the first of those instruments which the genius of this wonderful century invented and still more marvellously developed for the control and application of natural energies. In the aggregate, the powerful, complicated and delicate mechanisms and processes which we now familiarly and ignorantly employ in common occupations both necessary and trivial, are the visible evidences of a network of irresistible forces, in the meshes of which all humanity is now so securely entangled that it cannot possibly escape. Nothing is so pitiful as our boast that we have conquered nature. We have opened the bottle of the Jinnee; and the grim, inscrutable giant whom we have released is compelled by fate to serve our needs and pleasures; but because he serves so well, he also con-

trols our destiny: we command, but are at the same time enslaved. He does the work of a thousand craftsmen, and these have lost the joy of labor; he forces coöperative effort, and men lose their individualities and think and act in herds, crowd by the million in magnificent, ugly cities built of steel and stone, suffocated, deafened and begrimed; he yields them riches and defiles the fair face of nature, multiplies their sensuous pleasures and deadens their sensibilities, intensifies equally their productive and their futile activities, tightening, stretching and breaking down their nerves and brains; and thus, while he empowers charity to strengthen the weak and diseased whose numbers he has multiplied, he substitutes for the cruelly destructive but reinvigorating processes of nature an artificial selection which destroys the highly organized and preserves the unfit. He bridges time and space, making the world smaller, bringing into contact and binding together with his web of competitive trade peoples of irreconcilable habits and traditions, and of still feral temper, fattens them with new comfort and leisure, and watches them multiply, bragging of great populations; and when at length they spring at each other's throats and fight, he places in their hands the weapons of decimation.

The practice of this new magic thus evidently has wrought not only abundant good, but compensating evil also. It is wise to face the evil, for it is always immanent. The joy of great achievement is a subtle intoxicant: it is well to beware of it, to keep our senses alert and to know our dangers. But not to fear them. Fortunately, the same influences that have brought

these dangers upon us have given us the confidence boldly to meet them. If they have forced an intensification of our activities, they have correspondingly quickened our alertness, intelligence and resource. The struggle for mere livelihood now necessitates training which formerly was unnecessary, and has developed among ordinary men a keenness of apperception and an adaptability and decision of character which was quite uncommon half a century ago. The relative number of technically educated men has been many times multiplied; for handicraft has been mechanically developed and systematically organized, new individual occupations of quasi-scientific character have been born of successive inventions, trades have become professions, and professions theoretically elaborated disciplines. There is no longer any great distinction in becoming a college graduate; for the upbuilding and guiding of our industries and financial institutions and for the directing of our governments we now demand the services not of bachelors of art but of doctors of philosophy. Merely to maintain and operate the complicated machinery which enchains the natural energies now placed at man's command calls for a high order of ability; to control it advantageously and to anticipate and meet the constantly changing economic and political situations which arise as the field of its application is extended and developed overtaxes the ability and wisdom of the greatest men. We are not as yet equal to the task; but the measure of our success in controlling the immediate effects of our dangerous exercise of newly acquired power encourages the hope that we shall in the end secure our-

selves against the final disaster which we do well to apprehend. The labor will be incessant, but our abilities and our endurance cannot but grow with the wisdom of experience.

We are, moreover, no longer working wholly at cross purposes. With the quickening of the common intelligence, and the corresponding sloughing-off of inhibiting prejudices — tribal and institutional, religious and moral — we are impatiently breaking down one after another of our ancient social barriers, and half-consciously, through conflict and compromise, are more and more effectively coöperating for the establishment of conditions which will make for the increased security, enrichment and improvement of all human life. A new sort of social sympathy, no longer dutiful and labored but spontaneous, unsentimental, and wholly genuine so far as it goes — the normal product of coöperative work and unembarrassed understanding — adds its force to that of will and intellect. It is notable that the spirit which animates this movement is not primarily either altruistic or religious but essentially practical. The times are those of social readjustment: of industrial turmoil, economic revolution and war; the general indifference to the cultivated amenities of life which results from preoccupation with urgent affairs is paralleled by a corresponding lack of spiritual concern. In their hours of emotional stimulation men may still be dreaming of Utopia and Heaven, but in actual life they seek merely a *modus vivendi*. Yet once more they have stripped from their eyes the veils of illusion which imagination so persistently weaves, and see each other as they are; but

this time at last without dismay. The courage of the Stoic has returned, but much enhanced: for men know more now; they are burdened by fewer imaginary fears, the grip of custom and of old belief is loosened, and their social world is no longer fixed, but in the making. They seek, therefore, no new avenues of escape from life but choose rather to live; and to build afresh with the wealth and power which they now control in common, and out of the rough and resistant but not intractable material under their hands, a better actual world to replace the long-cherished figments of baffled hope and desire. And the power which they intend to wield in this struggle toward real salvation is neither sentiment nor faith, but practical intelligence; and its instrument is knowledge.

It was knowledge which in the primeval wilderness armed man against the beasts which were stronger than he, and made them helpless to face him; which protected him against the cold and the storm and dispelled the shadows of night where unseen danger lurked; which yielded him the fruits of anticipated times and seasons, the spoil of the sea and the precious riches of far-off lands; which developed the handicrafts that brought him leisure and newly productive thought, and at length the partial freedom of established civilization. This knowledge, unimaginably extended and detailed, now enables him by subtle means to avoid the catastrophes of land and sea, to stay the famine and prevent the pestilence: calamities which no goodness or virtue or sacrifice ever averted, and against which, throughout the ages, his desperate expedients of spell and supplication were wholly unavail-

ing. And now this knowledge promises, at last, his final emancipation. For not only has he opened the bottle of the Jinnee: he has searched the deserted labyrinth of the Minotaur; has explored the silent caverns of the Mysteries! The insatiable and reckless curiosity, which no timid appeal nor solemn admonition nor blustering threat could repress, by which he discovered the way to freedom and power, and best of all the entrance into a world of new strange wonders, has guided him to a surpassing wonder — and to a somewhat embarrassing revelation also.

It has to do with the Jinnee. He has felt the strength of this gigantic creature, both for good and for ill; his pulse still throbs uneasily even when he commands it — but now he has glimpsed its soul. This is a black pool, filled with vague moving shapes, grotesque, distorted, hiding from the light and only half revealed: not a pretty pool, but one which must be fathomed; must, because when he knows but even a part of what its depths conceal, his will can conquer every fear; for this soul of the Jinnee is nothing but a magic mirror which magnifies his own. And he will know in time: rest assured of that. He can confidently depend upon his precious curiosity, which has not failed him yet. To find the means for new enlightenment he has only to follow on and on the endless, twisting path, familiar yet always strange, by which he has come thus far, still trusting to its guidance. By this path long ago he escaped worse dangers than any which encompass him today, survivals of his primitive savagery he never even thought he could outgrow. Yet they are gone. He still remembers the ghosts and

devils that haunted his troubled dreams and filled his waking world with superstitious dread; he recalls the omens and portents that paralyzed his arm in the tense hour of danger; he still shudders at the horrid imaginings that drove him mad with fear and drenched the world with the pitiful blood of the persecuted. It was knowledge and knowledge alone that destroyed these fears; it was knowledge that drew the teeth of the vampires that fed upon them, and purged of their foul brood the beautiful temples of his hope and faith. And it is knowledge and still more knowledge which in the end will illuminate the depths of his still restless soul, and once more save him from himself.

And so the world is going back to school — to delve and marvel; to study, practice, invent and build; to search, to understand. The spirit of this brave company is eager, determined, generous, wide-visioned and altruistic, but animated in every mood by curiosity. It seems to be that of men new born: untrammeled and unafraid, impulsive and somewhat emphatically self-expressive — in a word, perfectly healthy. There is no vestige of aged asceticism about it; the surviving world-weariness and the cynical preciosity of their fathers have likewise disappeared. Their own particular affectation is nothing more harmful than a characteristic *sang-froid*. They have broken the chrysalis of subjective bewilderment, and are gazing at their wholesome, naked selves and out upon a far flung world with frank ingenuous interest; less troubled about their souls than about their future acts; not troubled at all by the eternal mystery, but skeptical, curious, inquiring. This is the scientific spirit —

in the making; untrained as yet, but eagerly demanding training. Only a few are fully aware of what is happening, but all are of one accord. Their younger voices sound the clearest note. We must listen to this call; for it comes to us from "those to whom the past is but the prelude to the play."

They are not forgetful, our youth protest, of their cultural heritage, but for a time they must remain content with its moral tradition. This still inspires even the youngest of them, for it is as thoroughly secular as the most incorrigible rebel could wish. It perpetuates no outworn tabus, no stale admonitions, and needs to be modified only so as to leave room for a little more self-expression to be perfectly satisfactory. Its authority is that of rich Experience, of real Life, that of a high and true Ideal; and they are still much given to ideals. It is, perhaps, as the self-critical among them say, rather fortunate that they have one thoroughly tested ideal to cling to. For the rest, "the poetry, the music and the dream," they are not prepared to deny that this also has high value; the unstudied products of their own spontaneous impulse and humorous experimentation certainly lack something; probably training, as the old fellows say. But this must wait awhile: there is so much else to be learned, so much that must be learned. It is knowledge that they want, and will have. They know that they have no culture, in any proper sense — not yet. They know that they will never develop a culture out of knowledge alone; but they know that the only culture that will serve future need must embody more knowledge than they now possess, incomparably more than any previous culture

has demanded. Man cannot live by intellect alone, they say, but he cannot safely live without it: that is — of course — one man may do so, or a majority; but someone in the community must have it and use it, for it is the intellect that keeps us out of trouble; that, after all, is its most important function. And our first business at present is just that: to keep out of trouble. We must master this great Jinnee, and ourselves. We cannot pretend that we do so now, but when we do, look out! As ancient Chicago said of culture long ago, we'll make it hum. Only, then, this culture must be a different thing. The old isn't rich enough; its quality is good but its body is too thin; it can never again occupy its former place. To anyone who has the time, the masterpieces of literature and art have lost nothing of their appeal — well, perhaps, something; but this may be regained. The point is, they explain, that, as the professor said, cultivated taste now demands, not only an aesthetic but a critical examination of the meaning and significance of these great works. The Iliad, the orations of Cicero, the Meditations of Marcus Aurelius, the Parthenon, the Mona Lisa, Wagner's operas, James's novels, the Woolworth building, Einstein's theory, and things like that, are to us not works of art alone, but records of civilization. What he said is really very true: the polite education of our grandfathers has been lifted to a higher plane. Between the vocational training which is necessary, and the aesthetic training that finishes the job, there has been interposed, as he said, a more thorough and more effective cultivation of the understanding; and this cuts both ways. We must know

more before we are sure that we are able to keep our big machine going without messing it up, and very much more before we can have a real culture.

Thus the younger generation. It is very true, indeed, what the professor said. He seems to have summarized the situation and with clarity and precision. We are witnessing a renaissance: the birth of a new humanism.

This, then, is the meaning of these fresh impulses and desires, this cheerful turmoil of eager endeavor which has quickened the pulse of the world. It is a new crusade of the human spirit. The full realization of all that this may imply brings with it a feeling of elation which is the infection of enthusiasm — but also, a tremor of concern. No high resolve alone can ever assure success. We cannot forget that other crusades have failed. It is necessary, then, that this one be wisely guided; and not only wisely, but shrewdly.

The burden of this responsibility of guidance falls upon the shoulders of the professor. This unobtrusive man who walks apart, thoughtfully detached or quietly observant, has been chosen, or has chosen himself (it is difficult to say which is the real truth) not to command this great movement, for he lacks both the inclination and the aptitude to command; but to devise its strategy. We may give him our full confidence. His air of gentle abstraction need not deceive us: he is not so unprepared as he looks. The insignia by which he might be recognized are accumulating dust in

some forgotten closet: he is a careless man, in little things. Otherwise they would remind us that he is no amateur in this business; that formerly he wore the cassock and the robe, taught princes their policies and multitudes their desire and will. This still goes on, and always for a Cause. His subtleties have never served vanities; but when, in emergency, he has thought it wise to mix in human affairs, he has usually, it must be acknowledged, been nothing if not efficient. We may, then, safely entrust our strategy to him. This will in the end save time and trouble; since, if we did not, he would probably take it gently but firmly from our hands—for here and now, once more, he has a Cause.

As a matter of fact he has already assumed this responsibility, having anticipated the event, our need, and our probable complaisance. His strategy is not, of course, yet formulated, for he works cautiously. He has, however, surveyed his situation and is already busy with the consideration of methods and devices which shall be flexible enough to meet such eventualities as may be predicted. In some of these we might perhaps be interested (at some other time) even though it were understood that they are provisional. But of immediate importance to us all is his preliminary survey. This, characteristically, takes the form of a somewhat crusty diagnosis, but that is good medicine: the methods of the competent physician are an excellent model for initial procedure in any investigation. Our self-constituted strategist, then, presents first of all his opinion on our preparedness; and confines himself, quite naturally at this stage of affairs, to

those general considerations which are of most vital concern: our resources, organization, discipline, and morale. His analysis of these matters, he says, determines at once and definitely the outline of his initial strategy: he therefore considers both of these aspects of his study together. The report is dry and technical, but it may be popularized. By ignoring his artificial categories, his tedious minutiae, cross-references and footnotes, and by synthesizing his general conclusions, it is possible to find sense in it, and not a little flavor.

We must begin, the professor assures us, at the beginning; that is, with the consideration of our antecedent higher culture, particularly with reference to its effect upon our mental attitudes and educational predilections. Its polite ideals are familiar: they are still prevalent in many of our colleges, and in the more conservative of these are accepted as establishing the sole criterion of general honors. Its influence is, therefore, still determinative among a large munber of cultivated people in fixing their standards of intellectual distinction. Now, this type of cultivation is very generally criticized, by those who call themselves progressive, as thin: by which it is to be supposed they mean lacking in substance, and by implication, lacking in vigor and fertility. This criticism, he warns us, need not be heeded even if its progressiveness be acknowledged, since progress is itself hypothetical. There is good reason to suspect, moreover, that it may express merely the impatience of men whose interests are too narrowly restricted. None the less, he continues, it is itself a sympton that is not without pos-

sible significance, and should be carefully scrutinized. The professor's scrutiny is minute: it occupies several pages of his report, and leads him at length to the conclusion from which subsequently he develops the rest of his analysis and his accompanying recommendations. Disregarding his careful qualifications of statement and extensive elaborations of argument, his substantial findings are these:

The criticism referred to is based upon the premise that the foundation of all cultural education henceforth must be significant knowledge. By this is meant what the scientist would call theoretical knowledge: that which deals not only with the substance, but with the essence of things, not only with appearances, but with causes; which is the result of dissection and analysis, comparison and generalization, and describes the inner nature of whatever is known so far as it is known, thus revealing the real significance of similarities and differences, analogies, contrasts, anomalies and singularities; which thus expands and develops not only our understanding of the limitless world of nature, but that of our still more mysterious inner world of thought and emotion, enriching for our immediate gratification and pleasure the meanings of common words and sayings, proverbs, aphorisms and treasured quotations — the fossils of man's past experience of life; giving clear meaning equally to the rough and vivid figures of our spontaneous speech and to our labored metaphors of aesthetic appreciation; and suggesting criteria of value more dependable than the precedents we usually accept as such, not only in art and literature, but in morals, politics and metaphysics.

This premise, says the professor, must be accepted. It merely defines the higher intellectual standard with reference to which, it is now commonly agreed, not only our scientific, but our entire humanistic education must henceforth be conducted. Such acceptance, however, by no means justifies the criticism we are examining. Though it be granted that in the order of events we have acquired new significant knowledge which ought to be incorporated in our cultural training, it does not follow — for popular logic may here be contradicted — that the training of our predecessors was, in its own day, deficient in this respect. Every cultivated man is certainly aware that the wide range of human experience which was embodied in the literature they most highly valued and appreciated needed only to be amplified by the results of their own archeological research and historical criticism to provide all the material necessary for the illustration and very thoroughgoing analysis both of ancient and of modern culture, in all aspects save the scientific; and mere recollection is sufficient to remind us that their more scholarly literature included, in addition to their greater classics, critical and philosophical works, scientific memoirs and histories of philosophy and of the sciences which were not only easily understandable but of high literary merit: human documents which, quite as effectively as the works more commonly read, would stimulate and develop both intellect and taste in exactly the manner that modern criticism would approve. It is obvious, therefore, that our predecessors had at their command means more than sufficient for the conduct of a human-

istic training comparable to the best that we could now devise; one which indeed would require nothing but the incorporation of modern scientific knowledge and discipline to make it fully adequate to meet our present needs.

If now, he continues, we examine with these facts in mind the formal education which our fathers called liberal, focussing attention upon its typical rather than its exceptional features, we are forced to admit that with reference to their own higher intellectual standards it was only too clearly defective. It commonly reflected, not the interests of their productive scholars and investigators, but those of their gentlemen — a very different matter. The conventional curricula out of which this education of a gentleman had grown constituted what was known as the classical education. This was what we would now consider a highly specialized group of disciplines, completely dominated by literary interests which in turn served primarily the purposes of the grammarian and rhetorician, and secondarily (that is, excepting when occasionally it developed this type of scholar) those of the aesthete. For it is interesting to note, he reminds us, that it rarely stimulated creative genius; that is, in striking contrast to our own most highly organized curricula, the scientific, it was not only specialized but relatively unproductive as well. Toward the end of the century this classical education was already breaking down under the pressure of those new interests, the slowly cumulative force of which is now concentrated in our present educational demand. Its influence, however, long remained dominant, and until

our own time determined the general tone of nearly all collegiate instruction. It thus continued the gentleman's tradition beyond its natural term, and so encouraged an easy-going superficiality in freely elective study; but, in itself, meanwhile, it uncompromisingly sustained, against this slackening, the full original vigor of that tradition. It thus embodied whatever severity of discipline college instruction still provided; since to the extent that it was replaced by studies less systematic and pedagogically undeveloped, all discipline inevitably declined in a general process of educational disorganization.

In the light of these observations, the professor concludes, the criticism of our self-styled progressive must be sustained. Our fathers' education certainly was too thin. In its traditional aspect it was altogether too specialized to serve the proper purposes of any liberal education properly so called; in its most liberal aspect it was little more than an accumulation of uncoördinated studies which stimulated fresh curiosities but provided little training; and in both aspects it exhibited a worse defect than either of these; worse, because it was a defect not of scope alone nor of method alone, but of both at once and of something more: a defect of vision, betrayed by the perpetuation of a literary standard of educational values, which was already an anachronism. This last statement, he says, demands elucidation; not because it is likely nowadays to be disputed, but because this literary tradition in education is either immediately or indirectly responsible for all the more serious difficulties which now confront us in the task of synthesizing our

higher culture. What the theological tradition was to the nineteenth century, the literary tradition is to us. We cherish no blind and vain desire to extirpate it; but we must finally loosen the lingering grip of its authority, or it is all up with us.

Liberal education, he goes on to say, implied to our fathers as to ourselves the acquisition of knowledge, but not usually the acquisition of significant knowledge, as the term has been previously defined. As a consequence of the over-long survival and domination of a Byzantine tradition which had infected Europe during the Italian Renaissance, and which during its extraordinarily protracted senescence had had an effect upon institutions of learning even more injurious than that of the scholastic tradition which it supplanted, education had come to mean all too commonly the acquisition of pleasurable, decorative and fundamentally inconsequential knowledge. The force of this influence was not derived from the enfeebled Eastern scholarship which gave it its intellectual tone, but from the fresh and vigorous humanistic impulse, already awakened in the West, which had assimilated this scholarship. The spirit of the new enthusiasm was not such as to encourage, excepting by the occasional lassitude of its young virility, any lazily impressionistic or trivially subtle habits of thought. It did, however, with characteristic extravagance, invest all human concerns indiscriminately with new interest and seeming importance; so that after its first impulsive energy had been spent in the resuscitation of the arts and in the fructifying of political and philosophical thought, and while in maturity its disciplined

and still inspired labor was building the foundations of our modern science, it continued to stimulate, particularly in the field of literature and under the direct influence of the old meticulous scholarship, labors of far less moment, the influence of which as time went on became magnified out of all proportion to their real importance, not only among those who sincerely cherished the classical learning, but also among the increasing number who desired to become cultivated without too much effort.

During the following centuries this cultural tendency was accentuated, in monarchical society, by its easy affiliation with aristocratic pretension, and in clerical circles by its acceptance as a relatively harmless substitute for scholastic erudition. Its consequent effect in later years was to encourage among the intellectual classes an indulgence of that natural eagerness for easily acquired distinction which has always characterized humanity at large. This lower motive survived the decline both of aristocracy and of theocracy. Educational institutions — particularly those colleges which meanwhile had become the recognized nurseries of social amenity — continued through habit to respond spontaneously to its unspoken demand; and throughout the nineteenth century, the age of revolution and discovery, the superannuated adepts in the old, old *litterae humaniores,* somewhat threadbare now but still urbane, maintained with easy composure throughout the academic world that amazing pretension to superior intellectuality with which for centuries they had deceived their preoccupied contemporaries, and themselves.

It is not to be inferred, the professor warns us, that this intrenchment of a somewhat emasculated humanism impaired, within the limitations it imposed, the quality of our forefathers' training. This inference, obviously, would contradict the evidence provided by their attainments. The moral and disciplinary value of the classical education was high. The early humanists had inherited from the Schools a thoroughgoing method which certainly lacked nothing of rigor; and this had been religiously developed, not only by the new classical grammarians but by the mathematicians and theologians whose ancient curricula had been retained as ancillary concomitants of the more highly valued aesthetic studies. This method provided a discipline sufficiently severe to mask for many years the essential weakness of their educational scheme. If it was inferior to that of the scholastics, it was certainly more effective than any subsequent discipline. In our own day it is well represented by college courses in Greek and Latin composition, formal logic, and pure mathematics. These are the only elementary studies which we have found it impossible to degrade by the application of democratic principles to liberal education; and they remain, therefore, our most effective means of redirecting the ambitions of the incompetent and sharpening the wits of the able. On this account in their introductory branches they are still very properly retained by the more responsible of preparatory schools as the best type of instruction at present available for the inculcation of that primary knowledge and aptitude which are essential to any productive work and for the development of the love of thorough-

ness and exactitude, the self-command and poise, without which our over-cherished self-expression now too frequently degenerates into a merely ridiculous babble and clamor.

It is unfortunate that this morale has not been transmitted to us unimpaired. The same process of liberalization which, wherever it was possible, eliminated discipline from newer elective studies had similar effect within the field of *belles-lettres;* but here it was unaccompanied by the stimulation of broader and more vital interests. It has already been observed that the rich material at the command of the classical humanist offered full opportunity for the incorporation within his educational scheme of those broader and deeper humanistic interests which had inspired the Renaissance. It appears, however, that the habit of specialization, reinforced by the always powerful desire for pleasurable self-gratification and by the less excusable though equally natural instinct for harmless display, were sufficient to prevent any such rejuvenation. Aristocratic tastes and weaknesses had been too long indulged. The same influence which had produced the gentlemanly student of history, philosophy and science, therefore, produced the dilettante in letters. It is for this reason that our retrospect must become somewhat remotely historical if we are to discover disciplinary value in the literary tradition.

Already in its earlier years this tradition had begun to suffer from the narrow restrictions which a growing academic preciosity imposed upon it. While in the outer world the original humanistic motive, with vigor unimpaired, continued to fertilize in countless ways

a rapidly widening and deepening learning, within the universities, repressed by theology and enfeebled by gentility, it too frequently became content to satisfy its waning desires with a merely reminiscent scholarship, and exhibited once more to a sorrowing world the impotent sterility of its Byzantine prototype. This atavistic tendency persisted, despite the vigorous academic growth of productive mathematical research, despite the forced intrusion of other scientific studies and investigations fostered by men of genius. These influences had little effect upon it. Habit was too strong. It not only perpetuated curricula of a type which had been outgrown within a century after the later revival of learning: with the gradual decline of its morale, its interest became more generally directed toward, and was finally focussed upon the art of literary expression. Beyond the range of those studies which contributed either to the improvement of this art or to the cultivation of the discriminating taste which encouraged its development, its scholarship became more and more conventional or casual: not seriously concerned even with the social and philosophical problems which the work of unfettered scholars continually brought to light, persistently hostile to natural science and every other agitation of common thought — indifferent, in short, to all matters save those of historical record or common knowledge which rhetoric might dignify, or verse and oratory beautify or ennoble: matters which we now recognize as the merely accidental, and in no sense the significant elements of human experience.

The harmful effect of this defective program upon

the subsequent progress of liberal education, the professor asserts, it is hardly possible to overestimate, since it perpetuated until our own time among the receptive and uncritical an implicit theory of values essentially false, which so far as serious and constructive thought is concerned was already obsolete three centuries ago. In recent years, the power of this obstinate prepossession has been slowly waning excepting within a diminishing circle of recalcitrants, primarily as a consequence of the independent growth and wide dissemination of quasi-scientific habits of thought in professional schools and in the world of affairs. It still exerts, however, a strong inhibitory influence upon the development of that synthetic humanistic education which alone can meet our present needs. It is necessary now, without further parley, to break this barrier completely down and pass through. This is not to recommend the fanatical enthusiasm of firecracker and tin sword. We could not, unless we were very young indeed, ignore the value of literary expression, if only as an essential intellectual discipline: to ignore the further value of that direct enrichment of our thought and emotion which is afforded by works of the imagination were not childish, but infantile. These studies are necessary in any education which pretends to be more than primary — even in that which is intelligently utilitarian. But henceforth they must occupy their proper place, by the side of other special and contributory studies. To neglect them would be most unwise, but we must no longer exaggerate their importance.

Their former commanding position must be occupied

by the sciences; not because, as it is sometimes represented, we, the people with whom wisdom will die, are or would like to be or pretend to be scientists; but because, after mature consideration even too protracted, we have decided that our first need is significant knowledge. To recognize this knowledge when we see it, and to know what to do with it when we have it, we must train ourselves; and our best available training is that of our great-grandfathers, amplified to include the methods of their productive scholarship, and adapted with proper care to our new purposes. It is only too apparent why our present scientific discipline will not serve this need: it is too particularized and uncoördinated. We are not eager to reject one form of specialization and forthwith adopt a variety of others. Our training must be no less sound, but generalized; more philosophical, which is to say more critical, though equally penetrative; and it certainly must be humanistic, for our purpose is humanistic.

The preceding considerations, continues the professor, define with very satisfactory clearness the problem which now presents itself to the strategist. This is to establish as the basis of our higher education what we must call a scientific humanism: its substance scientific, its method philosophical, its discipline scholarly, its spirit humanistic. This problem must now be examined with reference to the circumstances which most significantly affect the procedures for solving it. These procedures themselves cannot be completely deter-

mined in advance. As will subsequently be shown, it is probable that they must be derived not from general considerations, but from the results of special investigations and experiments; for it must not be forgotten that we shall be engaged in a methodological research. Such general considerations as those which we have already adopted to guide us may be accepted as dependable inferences from facts well known: we must, of course, be ready to modify even these in the light of further experience; but it is probable that as rough generalizations, at least, they will be confirmed by later cumulative evidence. It is quite otherwise with the methodological assumptions which we are compelled to make. These will be hypothetical, in the sense that they will be validated only by their accord with further experience and by their utility in suggesting new methods and devices; and we must look upon them, not as precious thoughts, but rather as wholly tentative guesses, to be abandoned, if they cannot serve us, with neither sigh nor tear. That is to say, our procedure itself must be strictly scientific. It will be, in fact, our first coöperative exercise in scientific humanism. To many this reminder will be quite gratuitous; but to a large number not so at all, since the mental attitude it exemplifies, though familiar, is not yet common.

To recognize in advance that our procedure must be thus pragmatic will also serve, perhaps, to allay certain doubts and apprehensions. We are so familiar with the wholly unnecessary afflictions we are forced to endure as a consequence of our passionate devotion to ideals that many of us, and paradoxically, the liberal-

minded in particular, too frequently fall victims to what may be called the innovation complex, and oppose by subconscious judgment *a priori* every novel suggestion whatever. It will probably soothe such fevered minds — the professor confesses that he himself is thus afflicted — to realize at the start that no ideal is embodied in his program; unless, indeed, the general acquisition of significant knowledge be considered such, despite his demonstration to the contrary. Ideals, he maintains, are usually either group prepossessions or violent projections of the personal will and desire into human affairs; and his criterion of intelligent education, he protests, is neither the one nor the other. Then resuming his argument: it follows, he says, that the establishment of scientific humanism in education by no means implies the abrupt disorganization of our present educational scheme, nor even its sensible disturbance. Even if it were not impossible to effect such change, it would be bad method to attempt it. The constructive processes of nature are evolutionary, not cataclysmic. If revolution is sometimes necessary in social readjustment, this is probably because human beings are both obstinate and impatient, as well as bellicose, by nature; that is, imperfectly adaptable to changing conditions. These imperfections of character are of course less common among the intelligent and educated; least of all, one would therefore assume — perhaps without great risk, despite what has been heretofore remarked — in academic faculties. There is, then, no likelihood that in the readjustment of our educational procedure any violence will be attempted, or if it were, permitted; and

there are means which accustomed skill can easily devise — indeed is already devising — to effect a gradual metamorphosis.

After this praeludium, he proceeds, it will probably be safe, for the sake of fixing attention more clearly on the difficulties which this readjustment must face and overcome, to consider the more important changes which its final establishment will necessitate. Let us then picture a contrast which after the metamorphosis has been effected, will be less striking and more difficult to define.

First of all, every humanistic study will include as the basis of its own philosophical development, and as the means of its coördination with other disciplines, a course, or preferably, courses in general science, carefully devised to provide essential information and to inculcate the scientific habit of thought. The inevitable tendency of such instruction to become superficial will have been anticipated and opposed by the judicious selection of topics, by the emphasis of generally significant detail alone, and by a stimulating severity of discipline. These courses having been designed with specific reference to their humanistic function, will finally have become thoroughly incorporated in the general plans of departmental instruction as prerequisite to advanced study; and higher courses purely humanistic, having meanwhile become more philosophical, will then illustrate, amplify, and thus thoroughly familarize the knowledge they have imparted. No difficulties other than those of design, coördination and pedagogical procedure are likely to present themselves in this readjustment, excepting in departments of

languages and literatures. In other humanistic fields the process of scientific development is already under way. It is probable that with respect to language and literature, a Fabian policy of benevolent infection will be the most effective, but this, of course, is conjectural. Despite the temperamental antagonism between the artistic and scientific minds, it may well be that the opposition naturally to be anticipated will not be persistently obstinate, since many scholars, and particularly those of executive ability, are not incorrigibly artistic.

Inasmuch as the new program will be primarily humanistic it will not, at any rate in its earlier development, have interfered with the organization of scientific instruction as such; although with reference to the advantageous liberalization of this instruction it naturally will have offered many constructive suggestions. Our scientific departments are now conducted to serve the wholly practical interests either of engineering or of research; and it is necessary that their present efficiency in this service be not impaired. It is certainly desirable to provide for those students of scientific inclination who wish to be liberally educated better opportunities than those now offered them to become so; but it seems probable that this may best be done by the amplification of their elective studies rather than by any hazardous attempt to modify their formal curricula. If this tender regard for scientific specialization presents itself to the humanistic mind as an inconsistency, two considerations will be sufficient to allay the suspicion: first, that scientific research is the *fons et origo* of that scientific knowl-

edge we desire; second, that common knowledge, which yields no scientific information or aptitude to the historian, philosopher or literary man, does provide the scientist with a considerable wealth of humanistic interest and stimulation — which, further, is not essential to the prosecution of his special work, as scientific knowledge is essential to the humanist in his particular labors. That scientists ought to be liberally educated is doubtless true; but it is likewise evident that since we must, for practical reasons, be especially careful not to impair their efficiency, it is better that their overspecialization be the last to be attacked. For the reasons given it is less harmful than that of the humanists; and a single group of narrow specialists may be easily put up with, especially in consideration of the fact that the social effects of their activities will be controlled by the humanists in any case.

On the other hand, the ultimate establishment of more liberal elementary courses in science cannot be avoided. It is necessary to our purpose that the humanistic liberalization of scientific studies be powerfully advocated and actively encouraged, and at once; for the obvious reason that we must depend upon the scientists to devise our basic cultural courses in science. It would be fatal to depend on others: both popular and philosophical literature speak emphatically to this effect. But it would be, if not fatal, at least seriously injudicious to assign this critically important work to men who could not thoroughly understand both its purpose and the detail of its adaptation, or who lacked the sympathy which inspires the ingenious devices of effective presentation. We encounter here

a serious difficulty: our most important propagandists are not yet trained. We can, of course, for a little while depend upon the services of eccentrics, who though scientifically educated, have yet kept alive an active interest in scholarly concerns. Such men, however, though common enough a generation ago, are now fast disappearing. Their place is being taken by philosophers and scholars of scientific inclination; but the interests of these men, who are our ablest and most influential advocates of scientific humanism, are for the most part, and at present necessarily, either metaphysical or antiquarian. Our first and most urgent necessity, therefore, is the training of humanistic scientists. This task is one which has never yet been attempted and will probably be very difficult of accomplishment, particularly since it will necessitate the introduction into scientific curricula, both elementary and advanced, of studies which to the now typical scientific mind are either uninteresting or repugnant.

Further, a general education of this character will demand of the student a concentration of effort comparable with that which professional training now compels. So far as the long-familiar unmodified course in arts is concerned, this improvement in tone will not, generally speaking, be unwelcome either to instructor or student, at any rate in those colleges where the student body is a selected group. In institutions where entrance examinations function as effective elimination tests, the intellectual tone of the undergraduate body is higher than it was a generation ago; its temper more serious, its outlook more mature. It is among such students that the spirit of scientific

humanism will be first inculcated — is in fact now being inculcated — and its establishment first effected. There is every reason to believe that no serious difficulties now stand in the way of the efficient organization of its curricula in these centers; and that, a higher standard of liberal culture having been thus defined, its influence will be quickly felt to good effect in institutions less favorably circumstanced. This new venture reflects a pervasive spirit of the times: it needs only to be given definite form to awaken a spontaneous and responsive support.

A very serious difficulty presents itself, however, when we consider the possibility of any more extensive adoption of scientific humanism as the basis of higher education. A rapidly increasing number of college students are preparing themselves for the professions, and in response to the increasingly exacting demands of the professional schools, are utilizing more and more habitually the opportunities offered by college courses to anticipate their elementary technical instruction. The more thoroughgoing cultural education which this new program will demand would appear to condemn these students to unremitting labor, unless the time which they now devote to the cultivation of general interests is meanwhile very considerably amplified; and to this adjustment both habit and inclination are undoubtedly opposed. The present tendency of collegiate training, which yields without resistance to the pressure of professional demands, is toward the reduction of the liberal education of these students to a safe minimum. The college no longer pretends to give them more than a taste of the human-

istic culture which a generation ago it demanded of all alike. It is obvious, then, that if in the future our highly educated classes are to include even a respectable percentage of broadly cultivated men still better informed, then this tide must be not only stopped, but turned. An ambitious project, certainly: one which would demand not individual courage alone, but cooperative effort on an unprecedented scale — and it must be admitted, with no great assurance of success. For here we encounter, not the passive resistance of academic habits which readily yield to new enthusiasm, but the active opposition of social forces, incomparably more intractable, and more powerful. The professional demand is itself justifiable: it merely expresses the unescapable necessity of more intensive training for the effective and, above all, for the safe utilization of our rapidly accumulating scientific knowledge. The curtailment of collegiate instruction to meet this demand cannot now be avoided. It must, however, be recognized as a dangerous maladjustment; since, speaking in the broadest way, it amounts in the end to the sacrifice of vision, judgment, caution, and even common sense, and in great measure that of resource and fertility also, to the mere acquisition of special knowledge. Difficult though the problem which it presents may be, it must therefore be courageously faced unless we shall be prepared to look with equanimity on the turning loose upon an innocent though culpable people of increasing hordes of dangerously equipped experts, deficient in wisdom. Their opportunities for harm will be limited in varying degrees, but by accident alone, since popular admiration

already grants them extreme privileges. One has only to picture the control of boards of health by men like these: with the power which another generation is likely to place in their hands, they might well make the activities of the Spanish Inquisition look like the cruel but relatively harmless pastimes of naughty children.

It is enough at this point, continues the professor, merely to state these problems. They cannot be solved out of hand: the fact should be reëmphasized that they are problems of research; inductive and experimental research, both minute and extensive. The establishment of the new humanism in our collegiate courses of liberal arts will demand coöperative skill, but will involve no great difficulty, excepting that of developing competent instruction; the coördination and humanistic liberalization of scientific curricula, on the other hand, will be opposed by a fixed habit of thought which will be the more obstinate because it is supported by the perfectly justifiable suspicion (a direct inference from past experience) that humanization means popularization, and therefore superficiality. In all probability this opposition will be salutary, since in the end it will enforce a discipline in all the new elementary scientific studies which inexperienced humanists will be likely to consider unnecessary; and also because it would stiffen coördinating courses, which otherwise might well become too desultory. It will, however, prolong the process of reorganization beyond any necessary or desirable period of delay, unless active and efficient missionary work shall meanwhile bring about a not impossible conversion.

Finally, the corresponding liberalization of collegiate professional programs will encounter the powerful opposition of common purpose and inclination, which the readjustment of higher educational curricula alone can probably neither circumvent nor overcome. Such opposition can be met and subsequently modified only by a general invigoration and quickening of our whole preparatory education; and this implies the solution of a complicated and very difficult social problem, which, it now appears, can be attacked (in the absence of an enlightened dictator) only by the extensive employment of vigorous propaganda supported by a consensus of all competent opinion. Such propaganda, however, must wait upon the adequate scientific education of teachers, which the colleges of liberal arts may in the future be expected to encourage.

Such propaganda may not succeed. In all probability their complete success is impossible, since they will encounter not only the impatient practicality and commercial ambition which are characteristic of all industrial society, but also that incorrigible love of excessive play which is our own particular and most engaging weakness, and the ultimate cause of our well known superficiality in so many occupations, those of the schoolroom included. If they do not succeed, we shall be forced to recognize in our more ambitious program of liberal cultivation the misdirected effort of fond illusion; and, reluctantly accepting the data which the regretful psychologist provides us, shall acknowledge that a people's capacity for education is limited; that the distended enrollments of our

universities do not signify so much as we had supposed; that the majority of our new academic residents wish merely to be made competent in some vocation, and that we actually have no right to inflict culture upon them. The task of the educator will then be once more reduced to normal dimensions. He will attempt not to enforce a general liberal education among all the highly trained, but only to preserve and extend the opportunities for its pursuit and to entice as many as he can into his snare. His accomplishment even then will be significant, and probably sufficient; for he will have bred still another variety of specialists — super-specialists in resource, good judgment and wisdom, whose superior abilities will probably more than compensate, even in social influence, for their meager numbers.

This summary view of our educational situation, the professor proceeds, clearly reveals as an indubitable fact the suspicion which has long been commonly entertained that our most dangerous intellectual malady at the present time is premature and excessive specialization. In our colleges, which are the centers where the new humanism already encouraged will first develop, the seat of this contagion, in its most dangerous form at least, is no longer the schools of language and literature, but the departments of science. Speaking professionally, — the prophylactic methods by which we are to protect our educational offspring against it, as well as the devices we must

meanwhile employ to reduce its virulence, will largely depend on our knowledge of its etiology. Its predisposing cause, we all believe, is dulness; but the absence of this condition — again professionally speaking — does not confer immunity. A lowered resistance occasioned by some economic need, an eagerness for material or social advantage such as is frequently recognizable in the symptoms of our common meretricious-distinction itch, even the twitchings of ordinary impatience may induce it. No one is really safe. In its incipience, diagnosis is difficult; the only treatment is careful nursing of the intelligence, or of courage where intelligence is unimpaired; and for the chronic form there is no cure. In this emergency all pertinent facts concerning it are of value, especially the historical, for these suggest the only general preventive measures which are likely to be effective.

This malady, like so many other malignant affections, had its origin in the East, and first became epidemic during the fourth and fifth centuries of our era. Its focus at this time was that Byzantine scholarship, the later modern progress of which has already been reviewed. It was the persistence of this literary tradition as a dominant influence in our universities which, by discouraging the study of the sciences as elements of liberal culture, established the conditions for their inevitable subsequent specialization. This responsibility is often unthinkingly placed upon the scholastics. No opinion could be more unjust. Their revival of Aristotelian philosophy in the thirteenth, their greatest of centuries, made Europeans for the first time familiar with theoretical science, and digni-

fied in Christian eyes the study of nature so long despised. It does not greatly matter with reference to our present concern, that the scope of this early inquiry was limited and its spirit in certain respects perverted by the influence of dogma, nor that its spontaneity was repressed by the age-long habit of dependence on authority. Science owes an equal debt to Albertus Magnus and to Petrarch; but the one is a debt of gratitude, the other a debt of revenge. From the time that the French nominalists resuscitated Euclid and Aristotle the physicist, and thus laid the foundations of modern mathematical science, to the time when the Jesuits disputed with Galileo and his successors their discoveries and theoretical inferences in astronomy and physics — and later still —, the scholastics contributed significantly not only to the actual development of science itself, but to the progress of scientific education. If the corresponding influence of those who called themselves humanists is to be adequately appreciated, it is not necessary to go back even to the early records of the Royal Society: it will be quite sufficient to examine the writings of Johnson and Swift.

In the bright but hazy hour of our present awakening, the professor resumes, we are likely not to realize how very recently the rude touch of nature disturbed the quiet rhythm of our pleasantly self-deceptive dreaming. It is within our generation that historians in their academic offerings have substituted for a mere narrative of dramatic events the critical examination of social impulses and adaptations, and have included in their educational programs instruction in the sci-

ences which had long ago revolutionized both their habits of thought and their scholarly methods. Even now philosophers, upon whom we depend for the most searching criticism of our profounder thought, are compelled by the inflexibility of our ostracized scientific courses to pick up at haphazard some positive knowledge about the phenomena with which this thought is immediately concerned; though all are well aware that in the past much of their most fertile speculation has been based upon such knowledge. And it is notorious that the best of our literary men, whose works future generations will first examine as evidences of the culture of our time, are still too frequently content to remain blankly ignorant of the temper and habit of thought which most significantly characterize it. In short, the serious and thoroughgoing investigation of the very foundations of criticism in the humanistic field has hardly yet been made a formal business.

The persistence of such scholarly bad habits has long been inexcusable; and responsibility for their continuance rests equally on scholars and scientists. During the last half century, as a consequence of our inadvertent admiration of German educational method, liberal courses of instruction in the sciences were firmly established and extensively developed in our universities as optional elements of our cultural education, though they were never incorporated as essential parts of it. The magnificent opportunities which these courses offered for the rejuvenation of humanistic studies were, however, largely neglected; and partly as a consequence of this neglect they have

since assumed, especially through the over-elaboration of laboratory methods which too frequently encourage hard labor at the cost of inspiration, a character distinctly repellent to all but the special student. They still exist, consequently, as self-determined and, very frequently, as completely uncorrelated disciplines, separately developed out of all relation either to the humanistic studies or to each other. They are to-day, even more commonly than thirty years ago, ignored by students of the humanities, and under the pressure of popular insistence are rapidly becoming more and more professionalized.

Under these circumstances scientific men, practically isolated in our universities, have become dependent for their opportunities, not so much upon the demands of scholars for exact knowledge, as upon the demands of parents for the vocational training of their young; and subsidized there and elsewhere by enlightened men of affairs, have gone their own way with somewhat irritating equanimity, and have established their more intimate *entente cordiale* where its spirit has been spontaneously encouraged: that is to say, extra-academically, among industrialists and merchants.

This association, which scholars are inclined unreflectively to disapprove, is, it must be acknowledged, a natural one; for modern science, which originated in the great world and penetrated the cloister and the lecture hall from without and with no little difficulty, has been developed for the most part, at least till very recently, outside the universities. The scope of its activity is larger than that of scholarship, and its

material achievement, especially since the industrial revolution, has bound it in increasingly intimate association with practical affairs. The far-reaching consequences of this association, which now determine the whole external character of Western civilization, are not in the common view to be regretted; but they have involved incidentally a further effect upon the progress of education which has been especially unfavorable to its simultaneous advancement. This effect is an accentuation of the divergence between culture and practical training which the spirit of literary humanism, agreeably with its Platonic predilections, had already emphasized; and the result is deplorable. The general tone of scientific activity, within as well as outside the universities, has become increasingly professional; its literature is growing more unphilosophical and technical, and the difficulty of securing for it the commanding position in cultural education which it must occupy before this education can become sufficiently instructive to serve our modern need is greater and greater. And reciprocally, these tendencies, without having yet seriously impaired the spirit of research threaten nevertheless to do so, since under the domination of our present industrialism it is more tempting than formerly for men scientifically inclined to divert their attention from that disinterested study of phenomena which alone may be expected to yield new knowledge, and to direct it toward the immediately useful application of knowledge already gained.

It must be kept in mind that the situation here outlined is one for which common interests are not in any particular responsible. It is, of course, inevitable that

the practical applications of scientific knowledge, which exhibit directly and obviously its effect on common life, shall appeal most vividly to the common man; but, however vaguely this man may apprehend the more subtle and profound effects of this knowledge upon the progress of his culture, his spontaneous curiosities are in no wise confined to the mysterious agencies which have recently placed the automobile and the motion picture, the airplane and the radio-telephone in his playful hands. The spirit of inquiry thus stimulated quickly transcends the limits of the merely pleasurable: fascinated and tantalized by the cleverly suggestive misinformation disseminated by common report, he demands authoritative elucidations of the most recondite of scientific speculations: on the structure of matter, the vagaries of the subconscious mind, the physiognomy of primitive man, the meaning of relativity, the shape of the universe. There has arisen, consequently, a wealth of new popular literature, good, bad and indifferent, which expresses the energetic determination not only of the people at large, but especially of the cultured classes, who with keener judgment take the matter seriously, to repair the too apparent defects of their formal education. The continued production of this literature deserves emphatically to be encouraged, if only to sustain the pressure of popular demand upon our institutions of learning. Its development and improvement, moreover, is in itself an important public service; for curiosities fostered and restimulated by entertainment often become persistent and, not as infrequently as is commonly supposed, lead to serious study. On the

other hand, instruction of this sort, which presupposes and embodies no discipline, can never transcend the limitations which common knowledge and aptitude impose upon it, excepting by the employment of didactic methods which, unless they are to endanger its effectiveness, must in some measure corrupt it by over-simplification and false emphasis. Such instruction, therefore, will invariably leave the critical judgment undeveloped, and will yield no insight into the essential character of scientific thought and activity. It will, accordingly, never gratify a serious interest in science, however effectively it may stimulate it. There exists, in short, no more for triumphant democracy today than for the autocracy of two thousand years ago, any royal road to knowledge. The avenue of popularization leads us only a little way into a region which soon becomes impassable and dark, across which the *ignis fatuus* of intuition sends only the faintest glimmerings.

This situation, the professor proceeds, has been for many years thoroughly well appreciated, not only by productive scholars but by the majority of those scientific men who have given it their accidental attention. Individual efforts toward its amelioration have been both energetic and persistent, and by no means unproductive of results, although the inertia of easy habit, which ordinarily determines the policies of institutions, has so far prevented the adoption of any thoroughgoing educational reform. The most successful of

these attempts have brought about, on the humanistic side, the practically complete reorganization on a sound philosophical basis of all collegiate instruction in history. On the scientific side they have effected the secure establishment in many colleges of courses in the histories of particular sciences, which have tended toward the broadening and humanizing of professional and technical training, and have encouraged occasional attempts to stimulate a more general interest in scientific studies by the introduction into the cultural curriculum of easy-going courses in general science, usually historical.

Of these two achievements that of the historians is certainly the more significant, because the reforms which they have instituted within their own field of instruction have been both radical and comprehensive, and have led them, consequently, as far as it is possible for any one group without assistance to advance toward the general integration of cultural studies. As indicative of the long step forward which they have already taken, it should be remarked that, under the direct influence of their present plan of formal instruction, historical students are contributing to our scholarly literature an increasing number of critical studies which bear intimately upon the development of scientific thought itself. Inspired by an inductive and synthetic habit of judgment which the curriculum now deliberately inculcates, the suggestions embodied in the more mature of these studies are singularly valuable as contributions toward the intimate correlation of scientific and humanistic interests.

Indications are not lacking that the same influences

which have brought about this educational reform in history are likely to effect a similar result in literary scholarship. The purely rhetorical and aesthetic interpretation of ancient literatures has now, through the stimulating effects of archeological and sociological research, begun to give way to a scientific examination of their deeper meaning; a similarly wholesome change of interest already affects the study of medieval writings; and it is not too much to expect that, when the significance of these developments shall be more generally understood, the scope of all literary criticism and of contemporaneous literature itself will be widened and deepened on the basis of a more inclusive formal instruction.

These observations apply, of course, exclusively to educational tendencies. In recent years, particularly, the historical and critical literature of science itself, not to mention a relevant humanistic literature much more inclusive, has been directly enriched by profound and invaluable contributions from individual scholars; but these, like the similar productions of historians, philosophers, and scientists philosophically inclined, are, generally speaking, isolated works of individual genius such as have never been lacking in previous centuries. They give but slight evidence of any general trend of literary interest, and as educational influences are negligible excepting in so far as they serve occasionally to stimulate new enthusiasm in mature scholars, to whom alone they can appeal, and by whose teaching their inspiration may at some future time be imparted to younger men.

From an educational point of view these activities,

taken as a whole, are more constructive than those of the philosophers, from whom, among the humanists, it would have been natural to expect the most effective labors. To those who await with some impatience the successful coördination of scientific and humanistic studies, it seems that the philosophers in the continued pursuit of their habitual preoccupations have neglected their educational opportunities, not to say their educational obligations. The general tone of their elementary instruction is not in the least scientific, nor even scientifically humanistic. It appears still to inculate habits of thought which are either imaginative or doctrinal, to the almost complete exclusion of those which lead by the way of philosophical skepticism to the development of scientific judgment. It perpetuates, in other words, the influence of all the venerable philosophical predispositions which are antagonistic to scientific thought, ignoring or slighting the criticism which has made them scientifically obsolete; almost as if its intention were to encourage among the educated classes a reactionary opposition to all empirical tendencies in philosophy by the continued cultivation of intellectual habits the unmistakable trend of which is toward the theological.

This conservatism in philosophical discipline, although to the scientist it appears reactionary, and to the dogmatist very encouragingly sympathetic, is properly neither: it appears, rather, to be merely the conservatism of habit. The mature philosopher is quite as well aware as anybody else of the fundamental importance of scientific knowledge in his own field of labor, and he is the last man who needs to be told that

its evaluation, which is probably the most important of all the tasks he assumes, necessitates an intimate acquaintance with its manner of growth. As the critic and interpreter of knowledge he has no desire to become a living anachronism: he knows, on the other hand, that to be a constructive philosopher he ought like the greater of his predecessors, to make himself, if not an active scientist, at least the guest and companion of the scientist, and to live with him in the closest possible intimacy. In his later years he cultivates this intimacy, and coöperates with the theoretical scientist in his most searching criticism and boldest speculation. The philosophical researches which this association suggests and encourages are recognized by every philosopher to be the most significant of any that he undertakes; for their purpose is the quickening of the critical understanding, the guidance of future investigation, and the extension of the field of knowledge and rational conjecture into realms yet unexplored.

These researches begin at the frontier of our actual experience, and naturally demand for their successful prosecution something more than an amateur's superficial acquaintance with contemporary scientific achievement. No intelligent purpose, therefore, can be involved in the philosopher's continued neglect of his elementary scientific education. It is mere carelessness which permits this, but it is a culpable carelessness. At present, the philosopher, despite his unquestioned acumen and subtlety, is very severely handicapped in the conduct of his most important work by the grave defects of his primary education. Ordinarily this leaves him ignorant of any but the

most obvious of natural phenomena, that is, only vaguely informed concerning the world of immediate experience which it is his business to interpret and explain; and furthermore, if the traditional instruction which he has received in formative years has taken full effect, he finds his critical judgment not wholesomely balanced by its influence, but definitely impaired. Not only is he obliged to acquire in maturity the very elements of scientific knowledge; he is compelled then to study for the first time the consistency of metaphysical opinions not in thought alone, but with reference to the totality of his experience, to examine his logical procedures also in an unfamiliar manner, to test the postulates of his formal ethics by the study of behavior — and this on the basis of a preparatory training which has systematically developed an attitude of mind and habit of thought which make pragmatic thinking exceptionally difficult and usually distasteful.

The effects of this gratuitous handicap upon the labors of philosophers are various. There are those whom it appears not to affect at all. These are the pragmatists; whose philosophy has been developed against a persistent scientific background by methods suggested by scientific procedure. These philosophers are hardly to be distinguished from scientists. Every scientist is, practically speaking, a pragmatist; and when he becomes fully conscious of his methods of procedure, and begins to analyze and criticize them, he may legitimately call himself a pragmatic philosopher. Alone among philosophers the pragmatists are thoroughly familiar with the scientific habit of thought; and they are its only dependable interpreters

to the world at large and to the scientist himself. They are, moreover, the most effective of all public educators who are working toward the general inculcation of a genuine scientific spirit among students of professional and social affairs.

The theoretical metaphysicians whose background is unscientific do not share the pragmatists' temperamental and acquired advantages in the prosecution of scientific studies; and they are further handicapped by the fact that their chosen work is not, like that of the pragmatist, principally methodological, but is on the contrary conceptually synthetic and interpretative. These philosophers therefore carry the heaviest burden of educational defect — not because they are less well informed than others in scientific matters, but because it is necessary for the effective conduct of their work that their scientific knowledge be thorough, if not indeed profound. It is they, nevertheless, who contribute to our critical literature the bulk of all its commentary upon science. This work is often surprisingly constructive as well as brilliant: eloquent evidence of the triumph of ability over education. It is inevitable however, that it contains a wealth of misleading suggestions and not a little misinformation concerning scientific theory; and this is particularly unfortunate, since of all writings on scientific thought these are by far the most popular and generally influential. They are affected by error, of course, in widely varying degrees; but almost none of them reveals an adequate nor even an accurate understanding of the spirit and method of natural science — that is, of science as all but mathematicians, logicians and

metaphysicians define it. Characteristically, they elaborate or else apply some one particular set of purely metaphysical postulates — logical, realistic, animistic or theological — all of which are either singularly defective as foundations for useful schemes of correlation, or are quite unsuited either to serve the practical necessities of research or to stimulate new investigation. No one of them, moreover, embodies or suggests a theory of inference which is in complete accord with the actual processes of scientific reasoning as these are revealed by the analysis of productive scientific investigations. They appear stranger to no man than to the natural scientist himself, and seem to him to express an intellectual predisposition entirely foreign to the temperament which has determined both the spirit and the method of his inquiries.

Despite these radical defects, this literature does not as a whole affect unfavorably the appreciation of science among cultivated men. Realistic, idealistic and other writings of similar temper are frankly metaphysical, and animistic interpretations of nature are likewise honestly extra-scientific. Whenever they are understood, they are interpreted correctly as attempts at far-reaching theoretical correlations as yet inapplicable in scientific practice: and, beyond encouraging persistence in attempts to visualize the fourth dimension or to picture curved space, or a finite universe, or a completed infinite, or the terminal geometrical point on a line segment — attempts which the popular extravaganzas of scientific men themselves have suggested — they do no particular harm. But the work of the philosophical mathematicians and

logicians, now widely popularized, is of a more dangerously misleading character, and causes the greatest confusion of thought among ingenuous readers not forewarned. Their doctrines, which exhibit the most insistent pretension to unqualified validity, which elaborate exclusively schemes of purely logical analysis confessedly indifferent or superior to all matters of fact, and which are conceived in a temper uncompromisingly hostile to that of the empirical investigator, are expressed in the common language of natural science and profess to elucidate the true meaning of its fundamental concepts. Thus they completely falsify the inadvertent reader's notion of the actual character of scientific reasoning and lead him astray.

It thus appears that the speculative philosophers as a group, and especially those among them who invoke most earnestly the scientific sanction, have contributed but little and perhaps in the final balance (speaking algebraically) less than nothing at all toward the clarification of humanistic thought concerning scientific matters. The cause of this is not far to seek. Their works have not interpreted the scientific attitude of mind and method of procedure for the adequate reason that they have not been written with any such intention. The speculative philosopher is not an interpreter, but an originator. If he calls himself a scientist it would be unfair to accuse him of any deliberate attempt to deceive, for he gives the word a peculiar meaning which is justified by archaic usage; and if he calls his doctrines science without qualification, this is because he actually believes that they *are* science properly so called, the methods and concep-

tions of physics and astronomy, chemistry, geology and biology being an erratic something else which he does not bother to name. He utilizes such results of scientific investigation as happen to interest him for the illustration and support of theoretical conceptions which lie far beyond the range of normal scientific interest and are his own peculiar business, much as the engineer utilizes for his contrasting purposes other results which appear at the moment to be practically useful. The point to be finally emphasized is that with respect to the further development of cultural education, the speculative philosopher is by his own volition exempt from responsibility: he cannot be accused of failing to interpret natural science to the cultivated world because, in fact, he has never attempted to do so. It remains to be said, however, that his work in itself possesses an educational value too commonly unappreciated, especially by students of the sciences. He perpetuates the most valuable of all ancient traditions — that namely of clear, consecutive, acute and dispassionate thought; and the discipline which his curricula provide is on this account superior to that of any other — unless the scientist, after an advisedly cautious self-examination, shall venture to claim a like distinction.

From all these evidences it would appear that the movement toward a more inclusive synthesis of cultural studies has already been not inconsiderably encouraged from the humanistic side. It remains to en-

quire as to what the scientists themselves are doing to promote it. Their task, unlike that of the humanists, is twofold. In order effectively to coöperate, they must not only strive to stimulate — or more properly to renew and keep alive — among themselves a somewhat more than casual interest in the humanities, analogous to the scientific interest which scholars on their part are beginning to cultivate; they must also make determined efforts to render the essentials of scientific knowledge accessible to all intelligent men, and still more earnestly assist, by liberal and authoritative instruction in fundamental subjects, in the more general inculcation of the scientific habit of thought.

The first of these problems seems, when it is casually considered, to be one of no great difficulty. The great majority of productive scientists today enjoyed during their years of elementary instruction opportunities for the cultivation of their philosophical, historical, literary and artistic tastes in no wise inferior to those which were then offered to their brothers in arts; if this training was collegiate the two were identical. At the present time it is still possible for the student of science to secure a similar preparatory training. It must be realized, however, that unlike the student of thirty years ago, he is influenced in a subtle and unfortunate way to reject this advantage.

The comparative isolation of the scientific courses in our universities has allowed full opportunity for that intensive development which the rapid extension of scientific knowledge in every field has encouraged, and in some degree compelled. As a consequence, the scope of these courses, even of the most elementary

among them, has become more and more narrowly restricted to the study of phenomena and techniques; and their numbers have been multiplied beyond any conceivable necessity by wholesome enthusiasm and emulation, as well as by competitive advertisement, so that academic energies and opportunities are now largely exhausted in the mere proliferation of mere knowledge. It has thus resulted that relatively few scientific curricula today offer the slightest stimulation of either humanistic or philosophical interests; and this specialization has already proceeded so far that, properly speaking, there exist no longer in our scientific schools any students of science, but only students of some one science who are preparing for the exclusive study of some particular aspect of that science, and in too many cases, only with reference to some particular practical application of this particular knowledge. That is to say, scientific education in our universities has already become, in the worst sense, professionalized. The inspiring general courses to which our older men look back with deepest gratitude have few successors. The knowledge acquired by the great investigators is still exhibited, but their spirit is not imparted; and the knowledge itself is usually neither synthesized nor interpreted, excepting with reference to its applications. Wherever the long-continued pressure of vocational demands has had its full effect, moreover, scientific instruction is not merely specialized: it has become inferior in tone. Studies which are not only professionalized but industrialized and commercialized as well, tend wholly to lose the character of genuinely scientific occupations. The degradation

of the spirit is too frequently followed by a progressive corruption of the intellect: the naked body of science is still exhibited — but cold, dead and mutilated, like some poor pallid specimen of the dissecting room, injected with dulness and preserved by formulas.

This horrid picture, fortunately, does not yet represent our typical academic scene. We pray that it may never do so. The spirit of free research continues to animate much of our professional instruction; and it may be that, by its means, we may save ourselves from this immanent disaster. Meanwhile, however, there is little room for humanity or philosophy, or for general science itself, in our scientific schools. If their corridors ever faintly echo the voice which speaks of the love of nature, this surely is because some absent-minded poet has wandered in and lost his way. The student whose spontaneous enthusiasm leads him impulsively into the web of their elaborate curricula is soon entangled. He is encouraged at once, both by the personal example of his associates and by the silent but authoritative suggestion conveyed by their programs of study, to look upon the indulgence of his unrestricted curiosity as a sort of feeble intellectual dissipation; yields almost immediately to the call of more insistent desire, and with little more than a timorous glance at his rather interesting but distracting surroundings, begins at once the arduous labor which is to prepare him for that wonderful voyage of unimaginable discovery upon which he has set his heart. Thereafter there is no time to play with culture. There is so much to learn — so much that must be learned. So he learns, and learns some more, and yet more —

and finally emerges, a highly trained but uneducated expert. It is in this manner that our colleges and universities, and not alone our technical schools whose proper business it is, are breeding specialists. There is, at present, no unequivocal evidence which suggests that scientists are men of inferior general cultivation; but it is highly probable that another generation will supply it.

It is clear that the persistence of these conditions not only impoverishes the scientific mind in a manner which makes the sympathetic understanding and effective social coöperation of cultivated men as a group increasingly difficult; it threatens ultimately nothing less than the serious impairment of scientific resource, intelligence and fertility. To check an influence so dangerous, therefore, a slowly increasing number of undiscouraged teachers are making determined efforts. Their first appeal is to the natural unrestricted interest and instinctive good judgment of the student himself. The unspoiled spirit of youth is not efficiently acquisitive: indeed it often seems that the narrowing of the scientific curriculum in our colleges, which easy custom makes too blindly uniform, is far from welcome to the majority of students in science, and is accepted stoically as a sort of preordained necessity. Forced too frequently to endure, in purely scientific and professional work alike, the pressure of a veritable strait-jacket of required studies, they become upon occasion unsparing critics not of the requirement as such, but of the conduct of the work — and always with reference either to a common overemphasis and tediously redundant exposition of details, many

of which have no educational value whatever, or to an equally common multiplication of laboratory experiments and problem drills which frequently become mere tests of endurance.

It is not the inept alone who voice these protests; who refuse to stuff their memories with isolated facts which they can easily look up when necessary in works of reference, and who cannily utilize the facile formula to short-circuit the meandering current of their unduly painful ratiocinations. Their objections are frequently the mere echo of those which their young grandfathers formerly raised against their own necessary training in grammar and syntax and prosody; but there is hardly a competent college instructor who will contend that, even so, they are quite unjustifiable. It is well known that much scientific instruction in our own day is going stale, exactly as literary instruction went stale two generations ago. Such restlessness, then, is evidence, not merely of a normal indisposition to work, but of an equally normal desire not to waste time in gratuitous work; and especially of an impatience, imperfectly apprehended, to understand the more general significance of tasks assigned and performed. For pseudo-intellectual occupation with non-essentials, and for difficult tasks overmultiplied and unexplained, the student would gladly substitute in part some other more suggestive and more stimulating work, which might yield him a clearer conception of the higher purpose and significance of his labors. That this is the real crux of his difficulties is made evident enough by his usual response to the efforts which are occasionally made to liberalize his

curricula. This response is one of expectant though tentative approval. When it is demonstrated that the less intensive courses offered are not too desultory and do not lead too far afield, they are accepted with apparent gratitude.

It is to this predisposition that the intrusive humanist appeals in his attempts to leaven the scientific dough which is the present source of our most widespread intellectual malnutrition. His most efficacious ferment, which serves the double purpose of digestant and carminative stimulant, appears to be the study of the history of science. The success of serious instruction in this subject is occasionally remarkable; and is often striking even when circumstances appear to require that it shall be undertaken merely as an incidental amplification of the usual teaching. The reason for this is apparent: it humanizes a sort of study which is uniquely severe and impersonal.

There is not lacking among mature scientific men a type to whom the whole great body of correlated knowledge which has been handed down to us is nothing more than a system of reasoned conclusions, satisfying in itself; in no more need of vitalization as a whole than is the beautiful structure of Euclidean geometry which is its first perfected part. These men, however, are, and probably always will be, in the small minority. The greater number turn more and more sympathetically as their productive work matures to the corresponding experiences of the men whose researches they develop and extend, and by whose thought and practice they are the more inspired as their own research becomes more original. Much

remains to be said on this matter. It is relevant to the present purpose merely to add that it requires something other than ordinary aptitude and attainment to appreciate, with an intensity sufficient to provoke enthusiasm, the cold and desiccated beauty of logical and algebraic demonstrations. On the other hand, any vicarious participation in the actual thought and labor which have yielded these results is a pleasure which may be shared by the ignorant and the learned, the ingenuous and the wise; for in all human experience the stimulation of the Work in Itself alone is universal and alone throughout life remains unimpaired. It needs only the quick interest which is excited by a lecturer's casual reference to his own or his colleague's investigations, to classical researches in any field, or to the conflict of current theoretical opinions, to make evident enough the common meeting ground of student and instructor. The study of the history of science satisfies the spontaneous curiosities thus betrayed; when seriously pursued, it yields an insight into the true character of scientific activity which no other study can so quickly develop; and finally, it provides the most efficacious means for the more intimate blending of scientific and other interests.

No methodical attempts have as yet been made to establish such courses as essential parts of our programs of scientific instruction. It is quite probable that it is not advisable to make this attempt, for much of their value might be lost unless, while recommended, they yet remained freely elective. Their firmer establishment, however, and their more thoroughgoing de-

velopment, which would advantageously involve more serious study of the growth of scientific ideas and methods, is necessary if they are to become educationally effective. Of importance in itself, such study quite naturally leads to the critical analysis and comparison of diverse scientific procedures, and thus directly to that correlation of our several scientific disciplines which is now almost wholly lacking. The establishment of general seminars, or other advanced courses of study devoted to this purpose, would not only rid our scientific curricula of the last of their particularistic defects, but would bring them into immediate contact with philosophical studies of similar character to mutual advantage; and would strengthen the bond by which the more elementary courses in general science now connect them with the humanities.

These and similar possibilities are as yet quite undeveloped: indeed, it is probably not too much to say that they are not even generally appreciated. And, in fairness to the scientist, the fact must be recognized that his reluctance to undertake instruction of this character is not wholly the result of professional preoccupation. The history of science, as it is usually presented in our most accessible text-books, is commonly a rather superficial affair; and, to be quite honest, is frequently so laden with antiquarian detail, ingenuous platitude or trivial gossip that it cannot long engage the serious attention of any thoughtful reader. The first impressions of the subject which one unfamiliar with its better literature is too likely to receive, therefore, are unfavorable. The point needs to be emphatically reëmphasized that the resist-

ance which is encountered in attempts to introduce this study into scientific curricula, is, from one point of view, not only justifiable but salutary. To serve the purposes of scientific humanism, the history of science must be made genuinely educative; and this cannot be done excepting by making it a scientific discipline rather than a bedtime relaxation.

It is not by the introduction of historical studies alone, however, that scientific education may be liberalized. Despite the persistent tendency toward professionalism which compels the immediate attention of the critics of our scientific schools, conditions are not by any means wholly unfavorable at the present time to the successful avoidance of its more dangerous consequences by reformation from within. The gradual intensification of scientific studies has been going on for several years, and the dangers it involves, such as have already been remarked, have not escaped the attention of scientific faculties. In many of our most wisely conducted institutions the stuffing evil has been markedly abated and even effectively corrected; in both laboratory and classroom typical problems have replaced the confusing profusion of illustrative examples, and are more critically examined, thoroughly and without haste, before and after performance; water is being squeezed out of over-diluted technical programs, and substituted by weightier matter; time is thus gained for the limited indulgence of relevant but non-professional studies; humanistic courses are recommended as electives to scientific students, and scientific courses are required in schools of commerce. Thus, generally speaking, men are now being trained

in many professional schools to develop, not skill alone, but resource.

These and similar changes in the character of professional curricula, though not yet common, are widespread. They are indicative of a new, or at least a newly prevailing trend of thought guided occasionally perhaps by broader cultural impulses not utilitarian, but more usually, and much more significantly, by professional interest. It is already beginning to be realized that in any occupation whatever ability must supplement knowledge if effective work is to be performed; that in all but a few callings resourceful men are more valuable than those who are intensively trained; and that premature specialization, therefore, defeats its own purpose. The several professional fields so overlap and interpenetrate that it is hardly possible today to master one without a general knowledge of many; and in the world of affairs every vocation is so involved with common social interests of all sorts, that general knowledge, paradoxically, frequently becomes the most efficient instrument of particular achievement. This is notably the case in executive work of any sort; and since power always rests in executive hands, it follows that the intensively trained expert is often so handicapped by the limitations of his education that even though he may be a man of high native endowment, he is more likely to spend his life accepting the orders of his inferiors and working for their benefit than directing his own affairs or even participating effectively in the conduct of coöperative undertakings.

Considerations of this sort show clearly enough that the same social conditions which have stimulated our

new enthusiasm for a scientifically humanistic education are likely to provide the natural opportunities for its establishment. If doubt remained as to the wisdom of our new purpose it would be dispelled by such evidences as these. The program of early specialization is no longer practical; it has suggested its own corrective. The encouragement which this significant fact affords us does not, however, release the humanistic educator from his responsibility. The natural adjustment of human institutions to changing conditions is always slow, and is usually imperfect: their metastable condition is peculiarly persistent, and in the absence of external disturbance seldom equilibrates itself by abrupt transition. In other words, unless we actually assist this promising tendency of spontaneous liberalization, the old condition may yet persist for years; and meanwhile the change is very likely to be incomplete. It will not suffice, if the process of adjustment continually lags a quarter of a century or so behind its appointed time. However conservative we may be by temperament, therefore, we must in this instance become agitators; and if we are called visionaries we must put up with it, remembering that in the vocabulary of the practical, very commonly, a visionary is merely one who can see beyond the end of his own nose.

So much for the scientist's first task: that of keeping alive and encouraging the growth of humanistic interest in his own domain. His further task of stim-

ulating generally among intelligent men an interest in scientific matters may be dismissed more briefly. His labors in popularization have already been discussed: these, though they are as yet for the most part fortuitous, are constructive and valuable within the narrow range of effectiveness which common knowledge and aptitude determine. It is evident, however, that the dissemination of more thoroughgoing instruction can be effected only by the incorporation of scientific studies as essential elements in the humanistic programs of our colleges, by the agency of which the teachers in our common schools will gradually become better informed in general science, and infected with its spirit. Only by this strategy may we hope, in the end, to inculcate among intelligent people at large the wholesome and invigorating habit of scientific thinking — that is to say, of equable, rational and practical thinking, informed by significant knowledge. This, of course, is the final goal of democratic education. It is not unattainable. By the procedure here recommended, the efforts of the teachers will be constantly supported by the collective interests of a growing body of seriously cultivated men and women, the influence of whose example alone might well become determinative.

It would be an inspiring task to elaborate extensively and in detail the progress of the scientist's labors toward this end: unfortunately, however, it is one which only an experienced journalist would dare attempt, for as yet he has done nothing. All such labor must await the solution of his more immediate problem: the thorough liberalization of scientific instruc-

tion itself. His efforts toward the solution of this problem, though significant, are insufficient: they have doubtless weakened the general tendency toward more intensive training, but thus far have failed to check it. He cannot expect to succeed until he manages to secure, as a consequence of the general reawakening of wider cultural interests among his colleagues in every department of learning, a purposeful and definitely coöperative assistance. That the spirit of such coöperation is awake among many groups of scientific men seems evident; that it is already active among the humanists there is ample evidence; it is stirring among the technicians themselves. The scientist's immediate problem, therefore, although it is the most difficult of all that the new humanistic impulse encounters, will probably not retard its progress overmuch. The specialization against which he contends is analogous to the old specialization of literary scholars in that, however dissimilar its origin and effect, it is, at least among cultivated men, the result of that almost universal shortsightedness which, contrary to common opinion, has its source not exclusively in intellectual limitation but quite as frequently in an over-enthusiastic concentration of personal interest. To correct it, it will be necessary, not to break bad habits long established, but to loosen the grip of new ones; and this, in ordinary human experience, is the lesser task. It must be realized, however, that these new habits are not, like the old, senescent, but vigorous, aggressive and sustained by group desires. They will not yield to particular measures of reform, but only to a general insistence among men of learn-

ing and influence; and will not be rendered harmless until through the medium of our schools of education a more liberal spirit and motive will have modified, to their betterment, the cultural inclinations of a receptive and fundamentally intelligent people.

All this assumes, of course, that these cultural inclinations are not already, from a scientific point of view, indifferent or even retrogressive. It must be admitted that this is an open question. No temperamental predisposition toward pessimism is implied by the perception that the present intellectual condition of men in the mass all over the world is one which exhibits in a very suggestive way that tendency toward moral decline which — with the reference to the similar condition of the later Alexandrian age — has been most aptly described as a "failure of nerve." In full consciousness of the hazards of historical analogy, it is impossible not to find in the similarities between our prevailing mental attitudes and those of the centuries which immediately preceded the collapse of Greek science, a source of some disquietude. The science of the nineteenth century, particularly its skeptical habit of thought, appears to be as unacceptable to our own philosophic mind as the simple naturalism of Anaxagoras was to the Socratics, or as sophistic pragmatism was to the Platonists, or as skeptical empiricism was to the Stoics and early Christian theologians. If one wished for any imaginable reason to appreciate Plotinus, he could do no better than first to steep himself well in our own mathematical theology and philosophical relativism. To the people, meanwhile, the scientific suspension of final judgment is as

impossible as it is to the philosopher, and scientific morals are altogether too stiff a dose. Subtle and simple both demand a comprehensible absolute, and the people will have, in addition, a world essentially good which shall ensure salvation to the irresponsible. The first insistence involves no further danger than that which is latent in an inevitable misconception of the scientific attitude; the second, however, is enervating. If modern science had no more to give mankind than the penetrating vision, sound method and promise which was all the Greek could offer, it would doubtless share its fate. The hope of the scientific humanist is that very religion of science which he cannot himself approve: the abundant faith of extravagant expectation which his actual achievement inspires. Nothing less than this, it is probable, would give the world sufficient stamina to work out its hazardous destiny. And this, says the professor, is yet another reason why it is not wise to be too precipitate in our efforts to reform the obstinate but productive scientific specialist. It is a cowardly motto, and he blushes to repeat it, but — safety first!

Our strategist thus concludes abruptly with no slightest attempt at either summary or peroration, in the common awkward scientific manner. We shall, however, forgive him this trifling lapse, for his work itself is uncompleted; and consistency of form and substance is after all a sort of literary virtue. It probably has a technical name in rhetoric.

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NEW YORK

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